The Impacts of Natural Disasters

A FRAMEWORK FOR LOSS ESTIMATION

Committee on Assessing the Costs of Natural Disasters
Board on Natural Disasters
Commission on Geosciences, Environment, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1999

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The work was sponsored by the Federal Emergency Management Agency, Contract No. EMW-96-GR-0422. All opinions, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the Federal Emergency Management Agency.

International Standard Book Number 0-309-06394-9
Additional copies of this report are available from:
National Academy Press
2101 Constitution Ave., NW
Box 285
Washington, DC 20055
800-624-6242
202-334-3313 (in the Washington Metropolitan Area)
http://www.nap.edu

Cover design by Van Nguyen. Cover photo courtesy of the U.S. Geological Survey.

Printed in the United States of America

Committee on Assessing the Costs of Natural Disasters

ROBERT E. LITAN, *Chair*, Brookings Institution, Washington, D.C.
RICHARD A. ANDREWS, State of California, Sacramento
STANLEY A. CHANGNON, Illinois State Water Survey, Champaign
LLOYD S. CLUFF, Pacific Gas and Electric, San Francisco, California
RONALD T. EGUCHI, EQE International, Newport Beach, California
JAMES F. KIMPEL, University of Oklahoma, Norman
ANNE S. KIREMIDJIAN, Stanford University, California
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THOMAS C. SCHELLING, University of Maryland, College Park
RICHARD T. SYLVES, University of Delaware, Newark
CAROL TAYLOR WEST, University of Florida, Gainesville

Staff

JEFFREY W. JACOBS, Study Director
PATRICIA A. JONES, Senior Project Assistant (since July 1998)
SUSAN E. SHERWIN, Senior Project Assistant (through July 1998)

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Preface

In the United States, fatalities and injuries, property damage, and economic and social disruption resulting from natural disasters seem to have become a part of the nation's social fabric. Despite some successes in mitigating their effects, hurricanes, floods, drought, earthquakes, and blizzards and winter storms ravage parts of the nation nearly every year. The following natural hazards were among the defining events of the 1990s: the Northridge earthquake (1994), Hurricane Andrew (1992), El Niño (1997–1998), wildfires in California (1993) and Florida (1998), and the flooding of the Mississippi River (1993) and the Red River of the north (1997).

Somewhat surprisingly, however, the total economic losses that natural disasters cause the nation are not consistently calculated. Following a natural disaster, different agencies and organizations provide damage estimates, but these estimates usually vary widely, cover a range of costs, and change (usually increasing) through time. There is no widely accepted framework or formula for estimating the losses of natural disasters to the nation. Nor is any group or government agency responsible for providing such an estimate. This clearly represents a problem in setting policies for coping with and mitigating against disasters. If reliable data on the losses resulting from disasters are unavailable, it is difficult to gauge the cost-effectiveness of public policy decisions such as relocating residents out of floodplains or limiting development in hurricane- or earthquake-prone areas. Such data would help government agencies identify trends in the costs of disasters, making it easier to know if hazard mitigation measures were having the desired effects.

The Federal Emergency Management Agency (FEMA) is the primary federal agency responsible for helping the nation prepare for and respond to natural disasters. FEMA, other government agencies, the insurance industry, scientists and engineers, and federal taxpayers all have an interest in better estimates of losses resulting from natural disasters. Though data are available on a range of such losses, they are diffuse: several federal agencies and the private insurance industry collect data on disaster costs. A challenge in defining a consistent data set for estimating disaster losses is identifying which data should be included in the estimates. For example, if a bridge is destroyed by a hurricane, its replacement cost is clearly part of the event's total losses. But should economic losses to local businesses due to the lost bridge be included? What about the extra miles (and the extra cost of gasoline) that people must drive to their homes and businesses? Should the economic gains to a local bridge construction company be counted against the losses?

This committee was convened to provide an accounting framework for assessing the losses of natural disasters. In particular, the Federal Emergency Management Agency requested the group to identify "the cost components that, when combined, would most accurately reflect the total cost of a natural disaster event. To the extent possible the committee will identify the relative importance of the components for accurate characterization of an individual event and the significance of different components across the spectrum of hazards. The committee will also suggest possible sources for accurate cost information, regardless of whether data are generally available from these sources at present."

The committee carried out this charge through numerous meetings and consultations with experts from different levels of government and the private sector. This report is the product of its work. The first chapter provides an overview of natural disasters and their losses. Chapter 2 outlines what is known and should be known about the so-called direct losses of natural disasters which result from the physical destruction they cause to property and human beings. Chapter 3 addresses the more complicated question of measuring the indirect losses of disasters, or the various economic consequences beyond the immediate physical destruction in disasters, such as business losses and unemployment.

As formal research on loss estimation strategies is limited, it is worth noting that another study on a similar topic was conducted at the same time as our NRC study. The H. John Heinz III Center for Science, Economics, and the Environment sponsored a study on the direct and indirect costs of coastal disasters. Entitled "The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation," this report should be available soon after the publication of this study.

On behalf of the Board on Natural Disasters, I wish to thank Margaret Lawless and Stuart Nishenko from FEMA, who provided feedback and suggestions throughout the committee's 15-month investigation. We also thank Gary Kerney of Property Claims Services (PCS) in Rahway, New Jersey, and Alan Settle, mayor of San Luis Obispo, California. They spent a full day with the committee at its meeting in Irvine, California in March 1998, providing abundant information on insurance and damage estimation issues. Finally, we owe our thanks to literally dozens of representatives from various federal agencies who spoke to the committee at its first meeting in December 1997, and at a July 1998 session on federal roles in disaster response and loss estimation activities.

NRC staff members Susan Sherwin (through July 1998) and Patricia Jones (from July 1998) provided logistical support for all the committee's meetings. Thanks also to study director Jeffrey Jacobs, who guided the committee through its meetings and the particulars of the NRC study process. Finally, I wish to thank my fellow committee members for their enthusiasm, hard work, and intellectual support.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Harold Cochrane, Colorado State University, Fort Collins;
Fred Krimgold, Virginia Polytechnic Institute and State University, Falls Church;
Howard Kunreuther, The Wharton School, University of Pennsylvania, Philadelphia;
James K. Mitchell, Virginia Polytechnic Institute and State University, Blacksburg;
Frank Thomas, Loudon, Tennessee; and Victoria J. Tschinkel, Landers and Parsons, Tallahassee, Florida.

Although the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the authoring committee and the institution.

ROBERT E. LITAN, COMMITTEE CHAIR

Contents

Executive Summary

Despite the frequency and expenses of natural disasters, there exists no system in either the public or private sector for consistently compiling information about their economic impacts. The committee was asked to provide advice regarding which data should be consistently used in compiling estimates of the losses of natural disasters.

The committee recommends that any data collection effort focus on the losses as a result of natural disasters, or negative economic impacts. The *loss* from a disaster is a broader concept than its *cost*, a term that conventionally refers only to the losses that are reimbursed by insurance companies and governments.

We suggest that the following specific types of data be assembled according to the following:

- One agency of the federal government should be made responsible for compiling a comprehensive data base containing the losses of natural disasters, adhering to the structure outlined in Table 2–2 (see page 29) wherever it is feasible. The committee believes that the Bureau of Economic Analysis (BEA) within the U.S. Department of Commerce, in consultation with FEMA and other federal agencies involved in natural disaster preparedness, response, and mitigation activities, is best suited for this purpose.
- The types of direct loss data that should be included in these loss estimates are listed in Table 2–2. The loss data should be classified according to: (1) who initially bears the loss: government, insurers, businesses, individuals, or nongovernmental organizations (NGOs); and (2) the type of loss: property, agricultural products, human losses, cleanup and response costs, and adjustment costs. Distribution of Table 2–2 to parties affected by disasters for comment may produce additional items for which data should be sought and compiled.
- These estimates should be made with the input of the following groups: Property Claims Services (PCS), the Institute for Business and Home Safety (IBHS), and the National Association of Insurance Commissioners.
- Direct losses include quantified (and, where appropriate, monetized) losses to human life, property, agricultural products, cleanup and response costs,

and adjustment costs, such as temporary living aid. Special efforts must be made to assemble data on losses of uninsured individuals and businesses, a major gap in existing loss data.

- The Office of Management and Budget (OMB), in consultation with FEMA and other federal agencies involved in natural disaster preparedness, response, and mitigation activities, should develop annual, comprehensive estimates of the payouts for disaster losses incurred by federal agencies. This will allow the federal government to better track federal disaster spending, which in turn should assist policymakers to better plan for and budget disaster-related expenditures.
- Indirect losses of natural disasters, such as temporary unemployment or business disruptions resulting from physical damage, are currently diffuse and rarely quantified. Efforts should be made to regularly collect data required for estimating these losses.
- Efforts in the modeling of indirect losses should be strengthened. A microsimulation model for forecasting the timing of business closures and indirect losses should be developed. In order to provide baseline data to calibrate this model, a survey of businesses should be conducted to understand their likely responses and abilities to cope with disasters. In addition, formal models for simulating business and economic restoration following disasters should be developed.

A comprehensive, reliable data base on the losses caused by disasters would be valuable to several groups. Perhaps most important, a baseline set of loss data, together with cost and benefit estimates of alternative mitigation measures, would allow the federal government and individuals and firms in the private sector to design and implement cost-effective strategies for mitigating the losses from natural disasters. Insurers could certainly use the data to improve their estimates of future payouts associated with disasters. And researchers and experts in disaster loss estimation could benefit from a standardized data base that would enable them to improve estimates of both the direct and indirect losses of disasters. These improvements in turn would assist policymakers in their efforts to devise policies to reduce the losses caused by future disasters.

Beyond providing an indicator of total natural disaster losses to the nation, the framework for loss estimation described in this report would also provide detailed information on losses. A better understanding of issues such as who bears disaster losses, what are the main types of damages in different disasters, and how those losses differ spatially, are of critical importance in making decisions about allocating resources for mitigation, research, and response.

1

Estimating the Losses of Natural Disasters

The United States has experienced natural disasters since the nation's founding over 200 years ago. During the 1980's and 1990's the United States experienced numerous, expensive—and frequently deadly—natural disasters. These disasters and their impacts have become part of our history: the drought in the central United States in 1988, Hurricane Andrew in 1992, and the Northridge California earthquake of 1994 were the nation's three most costly to date. Through the course of this committee's study, the nation experienced a severe ice storm in the northeast United States, devastating floods along the Rio Grande and in southeast Texas, heavy rains and landslides in southern California, a five-week succession of wildfires in Florida, a severe drought in south and east Texas, and three major hurricanes which impacted the southeastern United States. The committee also conducted its study during the fabled El Niño of 1997–1998 (see Box 1–1). This warming of surface water in the central and South Pacific and attendant effects on global weather patterns was—rightly or wrongly—blamed for many of the nation's and planet's weather-related hazards during this period, and "some forecasters have warned the nation to brace itself for much more expensive disasters in the future" (Larson, 1998).

NATURAL DISASTERS: A BRIEF INTRODUCTION TO THEIR EFFECTS

Anyone who has lived through a major hurricane or an earthquake does not have to be told of a natural disaster's destructive impacts. People are often killed and many others are injured. Homes, office buildings, shopping centers, highways, and other physical facilities are destroyed.

BOX 1-1

EL NIÑO CAUSED NATURAL DISASTERS OF 1997–1998

A recent series of weather disasters were caused by the record largest El Niño of 1997–1998, an event to which several intense storms across the United States were attributed. The term El Niño ("the child" or "the Christ child") refers to a warming of surface waters in the eastern tropical Pacific Ocean. Through history, this pool of warm surface water periodically appeared off coastal Ecuador, Peru, and Chile near Christmas. The tremendous amount of energy contained within this water has the ability to disrupt atmospheric patterns throughout the region and across the planet. The El Niño which developed in the eastern tropical Pacific during the summer of 1997, and lasted through much of 1998, was exceptionally warm and ultimately "blamed'' for several weather-related disasters in the United States during that period.

As forecasted when the El Niño developed during June–August 1997, California was assaulted by a series of coastal storms and heavy rains causing floods, numerous landslides, and damages to the state's valuable agriculture, with losses totaling nearly $1 billion statewide. Florida, Texas, and other southern states were struck by a large number of severe storms and numerous tornadoes. Tornadoes led to more than 60 deaths, and El Niño-caused losses in Florida exceeded $500 million. A record early snowstorm swept across the High Plains in October 1997, and severe ice storms struck the Northeast in January 1998, creating losses in excess of $300 million and 28 deaths.

The effects of El Niño on storm activity occurred from September 1997 through April 1998. The property insurance industry identified 15 catastrophes (events each causing greater than $25 million) during the 8-month period ending in May 1998, when El Niño's influence on the weather had largely ended. The total insured losses by these catastrophes reached $1.7 billion. Even after the storm activity ended, more damages occurred. Widespread fires broke out in Florida during June, fueled by a heavy growth of underbrush caused by the unusually heavy El Niño-caused winter rains. FEMA relief payments reached $300 million by the end of March 1998 and 18 presidentially declared disasters occurred from the fall of 1997 through April 1998, and all were partly attributed to El Niño's influence on the atmosphere. El Niño events have become stronger and more frequent since 1980, certainly one reason for the increased losses from weather-related natural disasters over the past 15 years.

In true megadisasters—such as the Northridge earthquake in California or Hurricane Andrew in Florida—the destruction can severely interrupt work, traffic, and the daily routine of a large area for months and, to some extent, years after the event.

Experts in the field of disaster cost estimation use various terms to describe the effects of disasters, not always consistently. It is therefore important to define at the outset how these terms are used in this report:

- The *impacts* of a disaster is the broadest term, and includes both market-based and nonmarket effects. For example, market-based impacts include destruction to property and a reduction in income and sales. Nonmarket effects include environmental consequences and psychological effects suffered by individuals involved in a disaster. In principle, individual impacts can be either negative or positive, though obviously the impacts of disasters are predominantly undesirable.
- The *losses* of disasters represents market-based negative economic impacts. These consist of direct losses that result from the physical destruction of buildings, crops, and natural resources and indirect losses that represent the consequences of that destruction, such as temporary unemployment and business interruption.
- The *costs* of disasters, as the term is conventionally used, typically refers to cash payouts by insurers and governments to reimburse some (and in certain cases all) of the losses suffered by individuals and businesses. Losses suffered by those who are uninsured, those whose losses do not make them eligible for insurance payments, and those who do not receive government relief should be counted in any complete compilation of the impacts of a disaster—but these losses are not included as "costs," as that term is used in this report.
- The *damages* caused by disasters refers to physical destruction, measured by physical indicators, such as the numbers of deaths and injuries or the number of buildings destroyed. **When valued in monetary terms, damages become direct losses.**

The formal charge to this committee was to "identify the cost components that, when combined, would most accurately reflect the total cost of a natural disaster event. To the extent possible, the committee will identify the relative importance of the components for accurate characterization of an individual event and the significance of the different components across the spectrum of hazards. The committee will also suggest possible sources for accurate cost information, regardless of whether data are generally available from these sources at present."

Given the formal distinction made between losses and costs, the committee felt that its deliberations and report should focus upon the losses and human impacts of natural disasters (which include costs), rather than the costs alone. One important request of this committee was to identify those data which should be consistently collected in compiling estimates of a natural disaster's impact. The committee felt that these data should include not only the cash payouts from governments and insurance companies (costs), but also a wider range of impacts.

This report concentrates on how best to measure the economic losses in disasters, as they are either the most easily measured or the best understood. Nonetheless, it was recognized that noneconomic consequences of disasters, such as environmental impacts, can be very important and, in some instances, may exceed direct economic losses. Accordingly, a discussion on the environmental effects of disasters is included in Appendix A.

Studies of the impacts of natural disasters vary in their coverage of losses. Some measure only direct losses whereas others purport to include indirect losses. Despite the difficulty of comparing different loss estimates, it is useful to be aware of the significant impacts disasters—especially megadisasters—can have. Based on available studies, Table 1-1 summarizes the four most expensive natural disasters in recent American history.

TABLE 1-1 The Four Most Expensive Natural Disasters in the United States (in current dollars at the time of the disaster)

Year	Event	Reported Loss	Source
1988	Drought[a]	$39 billion	Riebsame et al., 1991
1992	Hurricane Andrew	$30 billion	Pielke, 1995
1993	Midwest floods[a]	$19 billion	Changnon, 1996
1994	Northridge earthquake	$44 billion	Eguchi et al., 1998

[a] Direct and indirect losses combined. Other estimates refer only to direct losses.

Table 1-1 is interesting, not only because of the magnitude of the costs of these large disasters, but also because it highlights their diverse nature: no single type of disaster dominates the list.

It bears emphasis that the loss estimates illustrated in Table 1-1 should be viewed as best guesses, for there is no official disaster cost accounting system in the United States. What information we have must be compiled from different studies that use different estimation techniques and raw data sources. In addition, although insured property losses tend to be estimated reasonably well, there is much greater uncertainty about uninsured losses, which can be substantial. This point is underscored in Table 1-2, which shows the top disasters ranked by their property insurance claims. Notice that on this list Hurricane Andrew ranks first and Northridge second. Neither the 1993 Midwest floods nor the 1988 drought even make the list because most of the losses in those events were not privately insured or were indirect.

TABLE 1-2 Ten Costliest Natural Catastrophes, Ranked By Insurance Claims Paid

Month/Year	Catastrophe	Estimated insured loss ($ Millions)
August 1992	Hurricane Andrew: wind, flooding, tornadoes	15,500
January 1994	Northridge, California, earthquake	12,500
September 1989	Hurricane Hugo	4,195
October 1995	Hurricane Opal	2,100
March 1993	20-state winter storm	1,750
October 1991	Oakland, California fire	1,700
September 1996	Hurricane Fran	1,600
September 1992	Hurricane Iniki	1,600
May 1995	Texas and New Mexico, Wind, hail, flooding	1,135
October 1989	Loma Prieta, California earthquake	960

NOTE: Dollar losses are stated in the year of the event.
SOURCE: Insurance Information Institute, 1998.

The United States has borne significant costs not just from the major events shown in Tables 1-1 and 1-2 but also from the combination of the hundreds of smaller natural disasters that occur every year.

Catastrophes in the United States are identified, tracked, and reported by Property Claims Services (PCS), an insurance industry organization specializing in the property insurance business. PCS is best known for its work in catastrophes and is recognized internationally as the singular source of information concerning insured damage resulting from most major natural disasters in the United States. PCS also serves as the property insurance industry's liaison with federal and state government officials, consumer organizations, and the media regarding insurance issues associated with catastrophes.

Property Claims Services was originally a division of the National Board of Fire Underwriters, which initiated the catastrophe identification system in 1949. This system was developed to address the insurers' needs to quantify the impact of catastrophes on insurance coverages. As more Americans bought homes and moved to suburban areas after World War II, there was little information about severe weather events across the country. Since 1949, PCS has identified over 1,200 catastrophes affecting U.S. insurers.

PCS currently identifies a catastrophe as an event which causes $25 million or more in insured, direct property damage, and affects a significant number of property owners. This threshold has been adjusted through time: when PCS was founded in 1949, $1 million of insured, direct property damage constituted a catastrophe, in 1983 it was revised to $5 million, and was revised for a third time in 1997 to $25 million. For those events that exceeded the PCS definition of a catastrophe, the costs have increased as follows: 933 major events resulted in costs of $22 billion from 1949 to 1988; 312 major events resulted in costs of $79 billion from 1989 to 1997 (Kunreuther and Roth, 1998).[1]

The causes of the mounting costs of disasters in the United States (Figure 1-1) will continue to be debated. But certainly a major contributing factor has been the increased exposure of property and human beings to disasters. The nation's population has grown significantly since World War II, and more people than ever before live and work in disaster-prone areas—especially coastlines, floodplains, and seismically active regions. Various forms of economic development have also driven up the costs of natural disasters. For example, the destruction of wetlands, the clearing of forests for a range of human activities, and the paving of roads and parking lots all have increased the peaks of runoff from heavy rainfall. Furthermore, greater wealth means we simply have more to lose in disasters. Policymakers and citizens should be aware of these trends as they make decisions which affect the location of future housing and business developments. These societal trends help explain predictions of continuing increases in the losses from future natural hazards.

[1] These costs have not been adjusted for inflation and for changing insurance coverage.

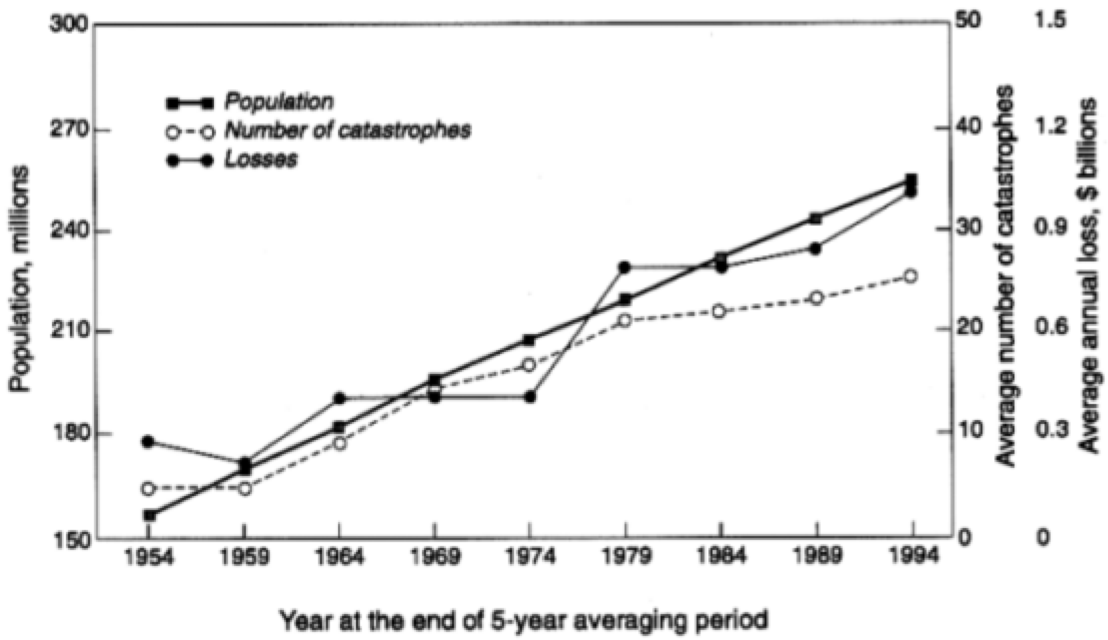


Figure 1-1.
The increasing trends—based on catastrophes that caused losses between $10 million and $100 million—for five-year periods of the number of catastrophes, the amount of loss from these catastrophes, and the U.S. population (Changnon et al., 1997).

WHY LOSS ESTIMATES MATTER

Who should care about disaster loss estimates, and why? There are several reasons which matter to different constituencies.

The *federal government* has a strong interest, on behalf of taxpayers, in accurate and comprehensive direct loss data. Largely through the Federal Emergency Management Agency, but also through several other agencies, the federal government covers a substantial portion of disaster-induced losses that are suffered by local and state governments, as well as by individuals and businesses, that are otherwise privately uninsured. Figures 1-2 and 1-3 provide data on federal government payouts from 1988 to 1997 and 1986 to 1997. As these figures demonstrate, FEMA provides only part of the federal disaster assistance effort. Other key federal agencies with disaster assistance programs include the Small Business Administration (SBA), U.S. Department of Agriculture (USDA), U.S. Department of Transportation (DOT), U.S. Department of Interior (DOI), U.S. Army Corps of Engineers (USACE), Department of Health and Human Services (HHS), National Weather Service (NWS), Department of Energy (DOE), and Department of Labor (DOL). [2]

Although extreme geophysical events cannot be avoided, their impacts can be reduced by government policies, or hazard mitigation initiatives such as reinforcing structures to enable them to better withstand the shock of an earthquake, elevating structures to reduce flood damages, land use planning to decrease structural exposures to natural hazards, and other measures. Because mitigation can be costly, however, it is important for policymakers at all levels of government also to be aware of the total *losses* of disasters—and ideally of the extent to which those losses can be reduced by various mitigation strategies—so that cost-effective mitigation strategies can be designed and implemented. [3] The same is also true for the private sector, where cost-effective mitigation measures can and should be used to reduce losses in future disasters.

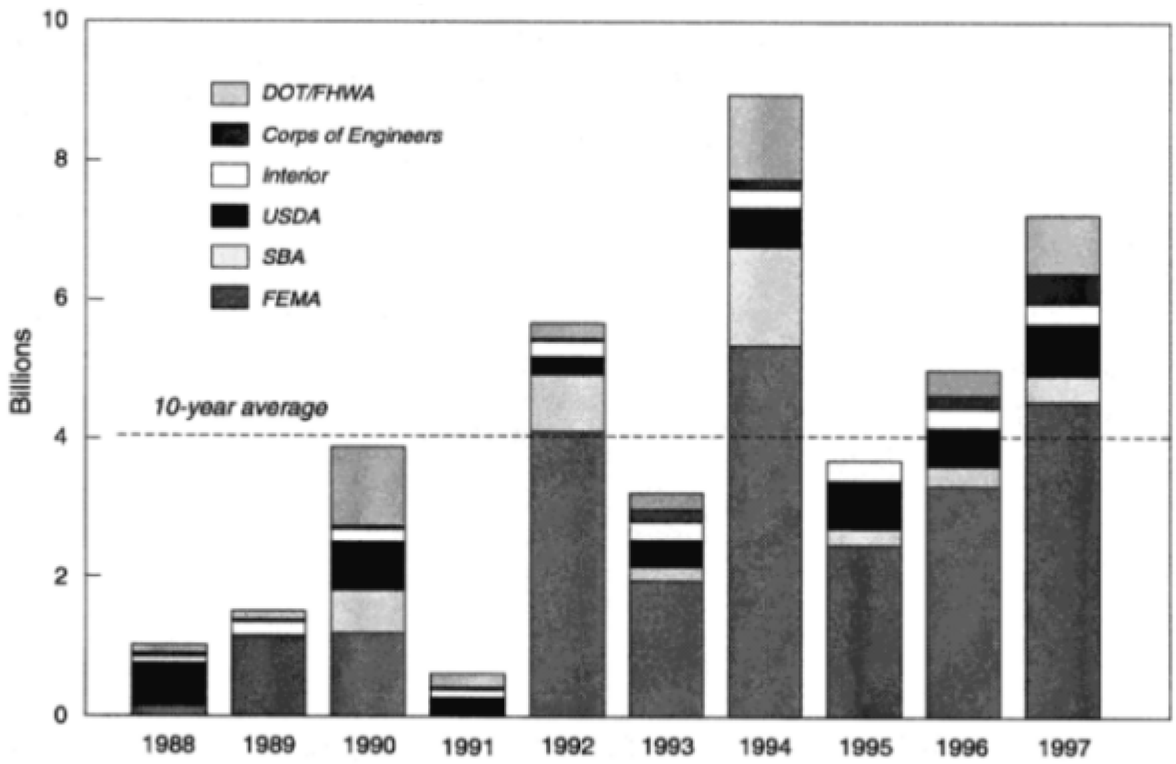


Figure 1-2.
Major federal disaster assistance programs (Rhinesmith, 1997).

[2] For a list of the most costly disasters (to FEMA), see Table 1-3.
[3] For a recent discussion of various mitigation techniques, see FEMA, 1997. In pursuing mitigation, policymakers should take account not only of the direct costs that such measures may avoid but also of the total disaster-related losses—that is, the claims paid by private insurers and government plus the uninsured losses that victims of disasters suffer (including, to the extent practicable, estimates of the indirect losses, which are discussed in Chapter 3)—that may be prevented.

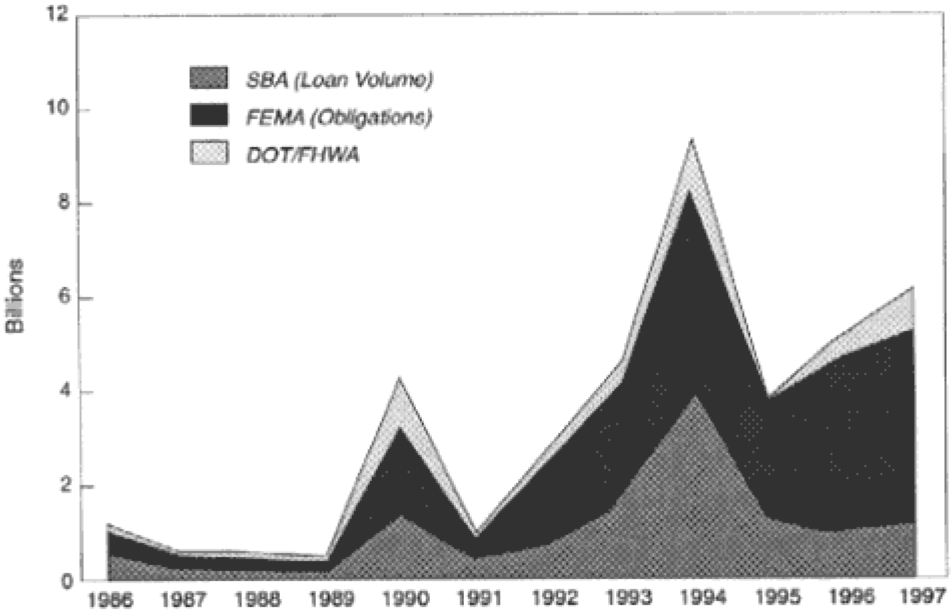


Figure 1-3.
FEMA, SBA, and DOT disaster obligations, 1986–1997 (Rhinesmith, 1997).

Policymakers should have an interest in accurate direct loss data for reasons that extend beyond mitigation. At this writing, Congress is considering proposals to establish a federal reinsurance program to support the private sector's supply of homeowners insurance for claims related to natural disasters (although critics of these proposals argue, among other things, that the expansion of reinsurance capacity in recent years makes federal intervention less necessary). If such a program is enacted, historical loss data will be essential both to potential buyers and the government (as the seller of the reinsurance, a type of insurance the government makes available to insurers to help protect them in the event of catastrophic events) so that all parties can be informed when bidding for or negotiating reinsurance contracts. An understanding of losses and their growth has been the basis for enacting foresighted legislation. *Ex post* analysis of the 1993 Mississippi floods, for example, led to needed revisions in crop insurance, flood insurance premiums, as well as broader programmatic changes in flood insurance.

Insurers clearly have a commercial interest in accurate data on costs covered under their policies: claims for property damage and related economic costs and for loss of life and injuries. Insurers also maintain their own payout data in order to operate their businesses. But to set actuarially sound rates, each insurer needs comprehensive data on payouts made by all insurers. Historical claims data must be combined with models that project the probabilities of future events over a range of possible magnitudes—as uncertain as these probabilities are—so that insurers can estimate expected future payouts.

State insurance regulators must know and be able to project disaster related costs in order to properly regulate or monitor insurance premiums.

Individuals and businesses have an interest in knowing the costs and losses of different types of disasters to help inform decisions about insurance, mitigation, and government policies for compensation of victims.

As mentioned, however, there is no comprehensive disaster loss information available from either public or private sources. Imagine if that were the case for statistics about the overall U.S. economy: no indicators of national or regional unemployment, output, or inflation. Policymakers would be severely hampered in their efforts at setting sound economic and monetary policies. Private actors in the economy would not know whether it was in their interest to increase or reduce their investments, consumption, or other economic activities.

Finally, *researchers* and *experts in disaster loss estimation* could benefit enormously from having a standardized data base of losses and other impact information that would permit them to improve their models that estimate both direct and indirect losses of disasters. Such improvements, in turn, would assist policymakers in designing cost-effective mitigation policies by simulating benefits and costs of alternative policies.

Fortunately, some cost data for natural disasters are collected in the public and private sectors. As discussed in more detail in Chapter 2, individual agencies of the federal government generally know how much they spend on compensating victims of disasters. So do insurance companies. But data are not now generally available for uninsured and indirect losses. More broadly, there is no comprehensive and reasonably accurate data base that pulls all of the relevant information together in a way that can be easily accessed and used by a variety of professionals. In making this observation, we do not mean to suggest that the federal government should create a data base containing loss information for every adverse natural event. Instead, the objective should be to compile data on disasters that cross some threshold. This issue is also explored in Chapter 2.

Who Bears the Loss?

It is important not only to assemble the total losses of disasters but to apportion those losses among all those who bear them—at least initially. Citizens and policymakers should know to what extent the losses are privately borne, especially through insurance, and what portion is paid by local, state, and federal governments. From the national taxpayer perspective, policies should aim to internalize to the maximum extent the losses of disasters—that is, induce individuals, businesses, and local and state governments to recognize and accept responsibility to purchase insurance (or to establish the functional equivalent of self-insurance pools) or mitigate such losses rather than to have the federal government come in after the fact and pay for the expense of reconstruction and cleanup.

But of course there are limits to the losses insurers bear. For example, although the typical homeowners' insurance policy covers damages to the physical structure of a home, some policies may not cover the entire replacement cost (unless such protection is specifically purchased). Homeowners' policies also may cover some, but not all, of the contents of a residence. In addition, private homeowners' insurance typically does not cover flood loss (flood insurance must be purchased separately through the National Flood Insurance Program, managed by FEMA), and it may not cover earthquake damage unless specifically purchased (and even then, coverage may be limited).

A common dilemma that disaster managers and policymakers face involves the issue of extending federal financial assistance to homeowners who refuse (or who are unable to do so due to low income) to adequately insure their property against disasters, despite warnings or previous experience with the same type of disaster. Extending federal assistance to those who did not insure and are financially capable of doing so discourages the purchase of insurance and the adoption of appropriate mitigation measures.

Starting in the late 1980's, FEMA received a regular annual appropriation of $320 million to cover the costs of its relief efforts. For fiscal year 1999, Congress reduced this figure to $308 million. FEMA's regular annual appropriations, however, seldom cover all the costs of federal disaster relief it is responsible for paying in a single fiscal year. Table 1-3 lists the ten costliest disasters measured by FEMA relief payments. Clearly, the sums shown in the table have greatly exceeded FEMA's relatively meager annual appropriations. FEMA has been able to make its payments only by receiving supplemental appropriations at various times. Until the Northridge earthquake, these supplementals were treated as emergencies for budget purposes and simply added to the deficit. Beginning with the Northridge earthquake supplemental request, Congress required all disaster supplementals (for FEMA and other federal agencies) to be offset with cuts in expenditures elsewhere.

TABLE 1-3 Top Ten Disasters Requiring FEMA Assistance (Through Mid-1998) [a]

	Event	**Amount of Assistance (in millions of dollars)**
1994	Northridge, California, earthquake	5,997
1992	Hurricane Andrew (Florida, Louisiana)	1,772
1989	Hurricane Hugo (North Carolina, South Carolina, Puerto Rico, Virgin Islands)	1,318
1993	Midwest floods	1,147
1989	Loma Prieta, California, earthquake	837
1996	Hurricane Fran (Eastern states)	560
1995	Hurricane Marilyn (Puerto Rico, Virgin Islands)	524
1994	Tropical Storm Alberto (Alabama, Florida, Georgia)	438
1997	Upper Midwest floods (Minnesota, North Dakota, South Dakota)	425
1996	Mid-Atlantic and northeast floods	366

SOURCE: FEMA, 1998.

[a] The table excludes Hurricane Georges because payout data were not available at the time the report was prepared. The dollar figures are in nominal terms (and thus have not been adjusted for inflation).

It is important to keep in mind that the federal government is not the only level of government involved in providing disaster assistance. Local and state governments also shoulder significant responsibility for managing emergencies. Federal agencies, particularly FEMA, stimulate and guide emergency planning efforts, furnish substantial response and recovery funding, coordinate response efforts after (and sometimes before) a governor secures help from the president, and fund many disaster mitigation endeavors.[4] In addition, significant costs are borne by volunteer disaster relief organizations, which are important sources of loss data.

[4] For a discussion of the various sources of disaster relief see Kunreuther and Roth (1998), pp. 10–11.

2

Direct Losses of Natural Disasters

This committee was requested to identify the cost components that, when combined, would most accurately reflect the total cost of a natural disaster event. The committee thus identified the data it felt should be consistently used in compiling accurate loss estimates.

The committee acknowledged that many of the losses in natural disasters are intangible and difficult to quantify, such as personal anguish, the loss of family treasures, and the disruption of family and work routines. Indeed, these losses may sometimes be greater than the losses of direct physical destruction. Despite the importance of such losses, however, the great difficulties in objectively measuring them make their use in consistent and accurate loss estimations problematic.

The committee's recommendations for those data to be used in compiling accurate loss estimates thus focus on *direct* losses, as they are easier to objectively measure. This chapter is devoted to direct loss measurement and those direct loss data which should be included in loss estimates. Chapter 3 is devoted to an assessment of indirect losses and ways in which indirect loss estimations might be improved.

As discussed in Chapter 1, it is useful to distinguish between the *physical destruction* caused by natural disasters to human beings and property, which is the subject of the current chapter, and the *consequences* of that destruction, considered in the next chapter. In economic terms, physical destruction may be thought of as a loss in *asset value* (and is often referred to as the direct loss from the event), whereas the consequences of that destruction may be considered to be the loss of *income and/or production* and impacts on the environment that cannot be readily stated in monetary terms (all of which are included among a disaster's indirect impacts).

So-called direct losses in turn consist of two more refined types of losses. *Primary direct* losses are those resulting from the immediate destruction caused by the event, such as shake damage from an earthquake or water and wind damage from a hurricane. *Secondary direct* losses are those additional impacts resulting from follow-on physical destruction, such as fire following an earthquake (due perhaps to breaks in gas lines) or additional water damage to unrepaired structures from rain following a hurricane (as happened after Hurricane Andrew).[1]

A third important distinction is the difference between reimbursed and unreimbursed losses from natural disasters. Reimbursed losses—referred to in this report as the "costs" of a natural disaster—include loss claims that are paid by private insurers or local, state, and federal governments. In contrast, unreimbursed losses are the uncompensated impacts that victims must bear. Different types of disasters tend to produce different proportions of reimbursed and unreimbursed losses. For example, a larger fraction of the total losses from earthquakes typically is unreimbursed—primarily because many consumers and businesses choose not to purchase insurance coverage and secondarily because insurance policies for these disasters typically contain large deductibles—than is the case for hurricanes and other wind storms. It cannot be emphasized too strongly that policymakers concerned with devising effective mitigation measures must take account of all losses, whether reimbursed or unreimbursed (and, to the extent possible, estimates of indirect losses, discussed in the next chapter).

Some natural disasters trigger the expenditure of additional resources devoted to mitigating future disasters. For example, presidentially declared disasters generally trigger FEMA expenditures on mitigation, provided they are matched to some degree (with some exceptions, as discussed later) by state and/or local governments.

In the balance of this chapter, we address three central questions:

- What information about the destruction caused by natural disasters should *ideally* be collected and reported?
- What data about the destructive impacts of natural disasters are *actually* collected and reported?
- What steps need to be taken to ensure that all of the relevant information about the destruction due to natural disasters is collected and reported consistently?

[1] In some analyses, what we have labeled "direct secondary losses" are treated as indirect losses. We do not do so here because such damage as is caused by fire following an earthquake or additional rain following a hurricane, for example, entails physical destruction, whereas the indirect losses we discuss in the next chapter all result from that destruction.

DATA RELATING TO PHYSICAL DESTRUCTION: THE IDEAL

Researchers seem never to have enough data. But collecting information is costly for those who must supply it as well as for those who must compile, organize, and distribute it. The challenge for policymakers interested in obtaining comprehensive and accurate data on the direct costs of natural disasters is to balance the benefits of allowing many constituencies (including the government) access to the information against the costs imposed on others (and the government) in attempting to collect and distribute it.

In principle, the desired data should be collected in a disaggregated form across several dimensions. Once collected, the data can be reaggregated and reported in multiple ways, depending on the purposes for which they may be used.

- Whatever data are compiled should ideally be categorized by type of disaster so that insurers, citizens, and policymakers can be informed of the relative severities and costs of the various events. In our judgment, these should be classified as hurricanes, floods (caused by events other than hurricanes), earthquakes, wildfires, landslides, volcanic eruptions, drought, winter storms, windstorms, hail, tornadoes, and all other events with losses above a certain threshold. Different kinds of disasters entail different types of losses and it is important in both the private and public sectors to be aware of these impacts.
- Similarly, all cost and loss data should be coded by the state(s) and, if possible, by county and zip code where the losses occur in order to identify where mitigation measures may be most necessary. In addition, state-specific data will be essential if the federal government is authorized to offer disaster related reinsurance to the private market, because it is possible that some coverage may be offered on a state or regional basis.
- For each major event (or annually by type of event, as the case may be), efforts should be made to collect and report data for both the type of damage caused, and which parties initially bear the losses (we stress the term "initially" because some losses are eventually passed forward to consumers). Natural disasters generally result in the following categories of destruction: to property (structures, contents, and transportation vehicles) with different types of owners (individual residences, businesses, and government-owned infrastructure);[2] to agricultural products (crops and livestock); and to people (injuries and death, life insurance payouts, and medical treatment expenses). In addition, disasters require expenditures for response and cleanup and temporary living expenses of displaced people. These losses are absorbed by insurers, governments,

[2] It would be useful to further disaggregate losses to structures (by type of building, such as apartment houses and single-family residences); to contents (equipment and inventory/supplies); and to infrastructure (roads, bridges, utilities, and transport facilities).

businesses, individuals, and nongovernmental organizations (such as charities and relief agencies).

- As a practical matter, some loss data that are now collected do not (and indeed cannot) distinguish between primary and secondary impacts. But conceptually the distinction is important. As an example, the roofs of homes blown off by hurricanes (a primary impact) will be covered by homeowners' insurance. A well-constructed home, whose roof stays attached during a hurricane, but is damaged by rising water (a secondary impact), is not covered unless the homeowner carries flood insurance. If the roof is blown off, it may be difficult to distinguish which caused the damage first—the roof being dislodged or the rising water.
- The definition of a "major" natural disaster (for which loss data are to be compiled) should be consistent. One definition would include all events that the president certifies as a "major disaster" under the Stafford Act (and thus whose victims become eligible for disaster assistance provided through FEMA), as well as events in which costs rise above a certain dollar threshold (such as the $25 million now used by PCS).[3] The Robert T. Stafford Disaster Relief and Emergency Assistance Act (P.L. 93–288, as amended) is the core statute under which federal emergency management is conducted. The Stafford Act authorizes the president to issue major disaster or emergency declarations, sets broad eligibility criteria, and specifies the type of assistance the president may authorize. There necessarily is some element of judgment required in deciding at what point to cut off the cumulating claims following a specific event or whether to treat a series of events—such as several days of heavy rainfall or an earthquake followed by several aftershocks—as a single event for purposes of satisfying the dollar threshold. Rather than offer specific recommendations for this problem, we suggest that the agencies we recommend be charged with additional data collection responsibilities (described later in this chapter) strive to ensure that the methods used for different types of disasters are consistent.[4]
- Measuring precisely the losses of natural disasters takes time. In the case of earthquakes, many victims may not know for weeks or months the extent of the damage their homes or businesses have suffered. Initial loss estimates may thus understate actual losses, potentially by wide margins. For example, it

[3] A more expansive definition could also include events certified as "emergencies" under the Disaster Relief Act of 1974. These are incidents requiring up to $5 million in spending for emergency work that is essential to save lives and protect property. An even broader definition would include the many thousands of smaller disasters that are declared by local and state governments (which the committee believes to be several times the number of presidentially declared disasters). The more expansive the definition, however, the more costly it will be to obtain timely and accurate data.

[4] Two approaches exist: (1) the PCS describes a weather system to tie multiple events on consecutive days together; (2) hazard analysts define the single most damaging event and add to it the lesser events that occur before and after.

was several months after the 1994 Northridge earthquake until many building owners realized that their buildings required major renovation. Ultimately, privately insured damages from that earthquake, initially estimated at $2.5 billion, exceeded $10 billion.[5] Any comprehensive loss data base should therefore be held open to reflect revised data (just as economic data are now revised, often years later, to take account of new information and methods of estimation).

- Ideally, not only should detailed loss data be collected for all major disasters, but an attempt should also be made to gather as much historical data as are available. The more complete the data base, the greater use it will be to all potential users—in government and in the private sector.

DIRECT-IMPACT DATA: THE REALITY

The reality is short of the ideal. The types of loss data that are currently collected, at least by some organizations (private or public), are reviewed below. We do so by identifying the sources of the data, classified by parties that bear those losses.

Insurance Claims

Disaster-induced losses typically are reimbursed to some extent by insurance companies. Many people who die in a natural disaster may have life insurance; others who are injured may carry medical insurance. In principle, these claims data are kept by the policyholders' insurance companies. As a practical matter, however, it is not clear to what extent these companies identify claims that are disaster related.

The situation is clearer for disaster-related property damage. The most comprehensive data base of insurance claims payments for property damage is the one compiled by Property Claims Services for catastrophe-triggered events. PCS has collected these data since 1949, using a dollar cost threshold to determine whether an event qualifies as a major disaster. If so, each event is assigned a number and claims for it are updated as they come in. As mentioned, the PCS threshold was initially $1 million and has twice been revised upward (to $5 million in 1983 and to $25 million in 1997). By these criteria, PCS has collected data on approximately 1,200 catastrophes. If PCS used a common threshold for the entire period since 1949—such as the 1997 cutoff of $25

[5] These figures are based on estimates supplied by a representative of the PCS who met with our panel in March 1998. For a more definitive account of the losses from Northridge, see Eguchi et al., 1998, p. 248.

million, adjusted backward in prior years for inflation—the total number of catastrophes in the PCS data base would be somewhat lower. [6]

The PCS data base is the most comprehensive one available for insured losses generated by natural disasters. One useful feature of the data is that they are maintained separately for each major event, by state. A drawback, however, is that the data combine rather than disaggregate losses to property, contents, business interruption and additional living expenses of individuals and families. Another drawback is that the PCS data base does not include damage due to floods, and it combines cost data for wind and hail storms and tornadoes.

Separately, the Institute for Business and Home Safety (IBHS) in 1994 began to compile more disaggregated catastrophe claims information, using the PCS dollar cost thresholds. The IBHS data base compiles actual paid losses of large insurers who account for most of the property-casualty market. Estimates are then made (using market shares) of the claims paid by other, smaller insurers. The IBHS data base has the advantage of breaking down damages suffered by businesses and individuals, to buildings and their contents, and by location (state, county, and zip code).

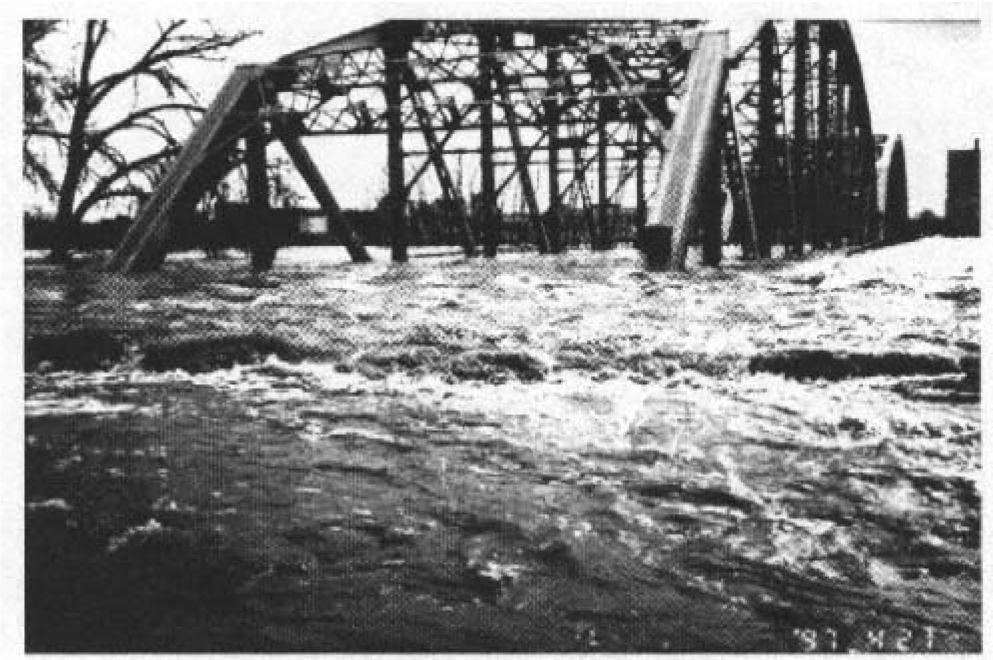
Neither PCS nor IBHS maintains data on insured claims paid to individuals for injuries and deaths. In principle, these data are available from medical and life insurers, but to this committee's knowledge, no systematic effort has been made by any organization, public or private, to assemble it.

We recommend that the agency charged with assembling the loss data make use of the PCS and IBHS data bases. To the extent the agencies find these sources of information inadequate, we recommend that the federal government work with relevant insurance trade associations and with state insurance commissioners (either with their trade association, the National Association of Insurance Commissioners, or the commissioners of individual states) to obtain data suitable for federal purposes. Since the data sought would be aggregated across insurers, it should not run up against the confidentiality concerns of insurers. The state insurance commissioners in particular should have an interest in cooperating with the federal government in a data collection effort, as they have direct responsibility for overseeing both the rates and the solvency of the insurers who do business in their states. In that capacity, they also have the legal means to compel production of the data. Working with the federal government to standardize data requests would ease the burdens on insurers while providing the government and the public with the information in the most suitable form.

One interesting complication with losses to insurers should be noted. In a worst case, some disasters could be large enough that they force the

[6] Without being able to examine the PCS data base, we cannot say by how much lower the total number of events would be. Separately, PCS also estimates the net insurance payments likely to be made following major catastrophes. This is a useful service, but the data that are of interest to us in this report are the *actual* paid insured losses that PCS compiles.

bankruptcy of one or more insurers (as was the case with Hurricane Andrew). In that event, claims on insurers would appear to exceed the losses that the industry actually bears. In fact, this is not likely to be the case. States have guaranty funds, which pay claims of failed insurers. These funds typically are financed by post-event assessments on other, surviving insurers doing business in the state. As a result, the insurance industry as a whole is almost certainly likely to bear all of the claims on it even though individual insurers might be forced into insolvency.



Flood overtopping Sorlie Bridge in Grand Forks, North Dakota, during the spring of 1997. (Photo courtesy of the U.S. Geological Survey.)

Losses to Government

All branches of government—federal, state, and local and tribal—bear losses associated with natural disasters, which fall into four categories.[7]

First, the largest costs are *disaster payments* made to individuals and businesses by the various governments, primarily agencies of the federal government. The main source of federal disaster aid is FEMA, which provides grants to individuals, states, and local governments suffering damage due to presidentially declared disasters. When the president declares an area eligible for

[7] This discussion is based in part on a meeting certain members of the committee and the NRC staff had with representatives of federal agencies involved in disaster aid and planning.

disaster assistance, FEMA makes money available to the states, which normally is conditioned on state matches of 25 percent of the total. The president may waive all or part of the state match, which often occurs in especially large disasters (as was the case in Hurricane Andrew and the Mississippi floods).[8]

FEMA can distribute, however, only the funds that are made available to it by the Congress through the appropriations process. In recent years, FEMA's disaster payments have significantly exceeded the agency's annual appropriation for such assistance (which, as noted in the first chapter, for the past several years has been $320 million, but in fiscal year 1999 was lowered to $308 million). The additional funds have been provided through supplemental appropriations, which until 1995 were added to the overall federal budget without offsets (reductions in other expenditures) in other federal programs.[9] Since then, Congress has required cuts in appropriations of other agencies to pay for supplemental disaster aid.

FEMA maintains current and historical data on the assistance it pays, by event, by state, and by type of aid: for infrastructure damage, payments to individuals for property damage, and payments to individuals for adjustment (temporary housing, unemployment, inspections, crisis counseling, and legal services). In addition, FEMA separately maintains data on grants and contracts for mitigation of hazards.[10] FEMA does not, however, maintain data on private-sector costs arising from disasters.

The Small Business Administration (SBA) is another important source of disaster aid, providing low-interest (between 4–8 percent) loans to credit worthy businesses and individuals (approximately 60 percent of disaster victims who apply) who have suffered property damage from a disaster. The SBA currently compiles its lending data by event and by type of property (and could, if given the resources, aggregate the assistance by type of disaster). The U.S. Department of Agriculture (USDA) also offers lending assistance to farmers and ranchers for losses to crops and livestock due to disasters declared by the president or governors. It is important to note that the true costs of federal loan programs are not measured by the total amount of loans disbursed, but instead by the present value of the interest subsidies on those loans.

[8] FEMA can lend money to states to help them meet the required cost share (where it is not waived). In addition, the agency reimburses certain other agencies for their disaster-related expenses, notably the Department of Labor, which provides unemployment compensation to individuals rendered unable to work by a disaster and who are not otherwise covered by the department's regular unemployment insurance program (such as agricultural workers, self-employed individuals, and recent entrants into the labor force). Unemployment insurance costs are part of the indirect losses we discuss in the next chapter.

[9] Under the Budget Enforcement Act of 1990, supplemental appropriations for disasters are exempt from the caps on discretionary federal spending if Congress designates the added funds for an emergency.

[10] For a list of disasters most costly to FEMA, see Table 1–3.

Second, governments bear damage-related losses to the *buildings and infrastructure they own.* To a significant extent, the federal government assumes much of the costs that otherwise would be borne by the states and localities. For example, damaged buildings owned by state and local governments (and certain nonprofit organizations) are eligible for compensation by FEMA if the disasters are large enough to merit a presidential declaration. The Federal Highway Administration (FHA) compensates states for up to 90 percent of the costs associated with the repair of roads if a disaster is declared either by the president or the state's governor. In addition, the Department of Housing and Urban Development (HUD) provides funds for repair of damaged housing and public facilities through its regular Community Development Block Grant program (some portion of whose grants some localities use for disaster recovery) or, in the event of large disasters, through supplemental appropriations granted by Congress.

The federal government also bears the losses of damages to property that it owns directly. Obvious examples include damaged federal buildings and facilities. Less known but often significant are damages caused by drought, fires, and floods to federally owned land and forests. For example, the Mississippi floods of 1993 caused $143 million in damages to federal facilities (Changnon, 1996b).

Third, all levels of government bear costs in *responding to disasters*, although for major disasters FEMA compensates local and state governments for their response and cleanup. In addition, FEMA reimburses the Department of Health and Human Services (HHS) for post-disaster counseling (although HHS provides a modest amount of health care assistance out of its own budget). And perhaps the largest response costs are those that fall on the Department of Interior, which typically spends several hundred million dollars a year fighting fires.

Finally, the federal government operates *two major insurance programs* that offer coverage—and thus make payouts—for certain disaster-induced damages. The U.S. Department of Agriculture provides insurance covering crop losses from a range of weather-related impacts (e.g., drought, flood, hail, excess moisture), and losses due to insects. The department collects data on loss payouts by type of crop but not by type of disaster. Meanwhile, the National Flood Insurance Program (NFIP), provides flood insurance to businesses and individuals in flood-prone areas. The NFIP includes three essential components: risk identification, hazard mitigation, and insurance. While the authority for the NFIP rests with FEMA, effective integration of these three components requires cooperation between the federal, state, and local governments and the private property insurance sector (Pasterick, 1998). By definition, the losses from this program are well identified with a single type of disaster (although it is not clear if the data on flood losses can be broken out by type of loss—that is, to structures, personal property, and the like).

The growth in the costs of natural disasters during the 1990's—both to the private sector and to the government—suggests that federal, state, and local governments should adopt a more systematic approach to data collection for their disaster costs. Such a data base would be useful for several reasons:

- A comprehensive data base and accompanying report would inform policymakers in both the executive and legislative branches, as well as the broader public, how sizable these losses probably are and clarify which government agencies actually deliver disaster-related aid and services. In addition, this information is critical for developing and implementing cost-effective ways to mitigate the losses of natural disasters.
- Comprehensive data on the federal government's spending on disasters would assist both the executive and legislative branches in budgeting and planning for disaster-related expenditures. The committee recognizes that members of each branch have incentives not to budget all such expenditures in advance, as there are political gains from appearing to take concrete actions in the immediate aftermath of a disaster, such as proposing and voting on large disaster relief supplementals (additional items in the federal budget). However, the short-run political gains have economic consequences: the supplementals require offsetting cuts in other programs in midyear, as has been the case since the Northridge supplemental considered by Congress in 1995. Offsets randomly interrupt the functioning of other parts of the federal government, delaying the delivery of services and potentially adding to the cost of implementing or developing government programs. The availability of a comprehensive data base, with suitable historical data, might enable policymakers to smooth out disaster-related costs by budgeting them at actuarially appropriate levels, with any surpluses banked in a reserve to be drawn down in years when actual payouts are larger than anticipated. But even small steps toward better planning, short of establishing a single or multiple disaster accounts in the appropriations process, cannot be taken until and unless the information is compiled.
- Assembling the federal government's disaster cash payouts data can also be usefully compared to the tally of losses absorbed by the private sector (insured and self-insured). Such a comparison would reveal the relative financial burdens of the government and the private sector in connection with disasters. It might also encourage greater use of insurance rather than reliance on taxpayer-supported government expenditures. As it is, the prospect that they might receive some disaster aid reduces the incentive of individuals and businesses to purchase insurance to cover such expenses. What many uninsured individuals and businesses may not realize is that although they may well receive some compensation from the federal government if they are victims of a major disaster, the federal aid is unlikely to be as generous or promptly paid as it would be if the individuals opted to purchase insurance. To the extent individuals and businesses in areas subject to catastrophic hazards are informed

of the limits of federal aid for disasters, it is possible that some who now are uninsured, perhaps out of ignorance, will buy insurance, modify existing structures to better withstand disaster impacts, or otherwise internalize risks that the government (and taxpayers) now carry.[11]

Losses to Businesses

To the extent businesses have insurance for property damage, their covered losses are included in the losses borne by insurance companies. Nonetheless, because insurance policies carry deductibles, even insured commercial operations suffer some losses, whereas businesses that self-insure for natural disasters absorb all of the losses themselves.[12] Business losses are, for all practical purposes, not covered by government disaster programs (though both homeowners and businesses can write off their uninsured losses for tax purposes). To be sure, the Small Business Administration and the U.S. Department of Agriculture provide loans for reconstruction, but a loan is still a loan, not a grant. Even businesses that qualify for federal lending assistance eventually bear the full losses themselves. In 1993 the flooded railroads in the Midwest experienced uninsured losses of $169 million (Changnon, 1996a).

In principle, insurers who pay claims made by businesses have the data to compute the total amounts of deductibles that their commercial clients must absorb, but no organization currently compiles that information. In addition, some federal agencies may have data on their disaster-related loans that could permit estimates to be made of the losses incurred by businesses that qualify for federal loans (although these data may not be disaggregated by kind of disaster, location, or type of damage—that is, to structures or contents). To the committee's knowledge, there is no organization that maintains data on disaster-related losses absorbed by businesses that self-insure.[13]

[11] FEMA has been attempting through advertisements in the major media to provide information about flood risks and to encourage individuals to purchase flood insurance against them.

[12] In addition, as described in the next chapter, some businesses may suffer lost sales *indirectly* as a result of a disaster, and these costs are not likely to be covered by insurance (nor are they treated as *direct* costs for purposes of this report). For example, suppliers to firms with plants or local infrastructure that are damaged or destroyed in a hurricane or earthquake may lose sales for some time until the facilities are repaired (although they may later experience a larger-than-normal level of purchases as firms with repaired plants attempt to satisfy some pent-up demand for their goods).

[13] Theoretically, some data on such losses should be reflected in the income tax returns that companies pay. But as a practical matter, this information—even if it is reported separately on tax returns—would not be broken down by event, location, or type of damage. Nor is it likely that the Internal Revenue Service could compile such data as may be reported.

Residential destruction resulting from the Northridge, California earthquake in 1994. (Photo courtesy of FEMA.)

Losses to Individuals

Finally, many individuals also self-insure some or all of their losses from disasters, although the extent of reinsurance varies by type of disaster. According to information supplied by a PCS representative, roughly 95 percent of buildings damaged by hurricanes are typically insured, whereas only about 10–15 percent of all California homes are covered by earthquake insurance. Similarly, most potential victims of flood damage do not purchase insurance through the National Flood Insurance Program. For example, in the 1993 Mississippi River flooding these numbers were disturbingly low: "in the counties and communities affected, it is estimated that no more than 10 percent of insurable properties had flood insurance coverage" (Wright, 1996). As with businesses, even insured individuals carry deductibles on their policies. Other individuals may receive some federal aid, which may or may not fully compensate their property losses and temporary expenses. And still other individuals and their families may suffer losses but receive no compensation from either private or public sources. For example, a 1997 winter storm caused $25 million of uninsured losses to property owners in Lincoln, Nebraska, and a 1996 snowstorm in Cleveland caused homeowners $5 million in uninsured losses (see Appendix A).

Again, in principle, insurance companies—property-casualty and medical—should be able to compute or estimate the total amounts of their deductibles for given events or types of disasters. Similarly, it should be possible for FEMA and/or other government agencies that now provide disaster aid to individuals to ascertain their total property damages. In practice, none of these data on self-insured losses absorbed by individuals are systematically compiled by any organization. The same is true with respect to losses suffered by individuals who do not qualify for or who do not seek either private insurance payments or government assistance.

Even more important than the monetary damages suffered by individuals in disasters are the injuries and fatalities that often occur. Through the National Weather Service (NWS), the federal government currently collects comprehensive data on injuries and fatalities in all weather-related events, however small. These data are provided to FEMA. As valuable as it is, the NWS data set contains two shortcomings for purposes of this report: it excludes fatalities and injuries from earthquakes and other geohazards, and it is not clear if the data on disasters below some dollar loss threshold can be easily separated from the larger disasters that, in our view, should be the primary focus of a comprehensive federal disaster data collection effort.

STANDARDIZING LOSS ESTIMATES

In addition to the lack of a comprehensive data base, there exists no standardized estimation technique or framework for compiling loss estimates from individual disasters. Most estimates are ad hoc, consisting of those losses that were significant in a particular event. As a result, the range of loss estimates of a natural disaster tends to vary widely, sometimes as much as 10-fold.

Table 2-1 is an example of one framework used in compiling a loss estimate for Hurricane Andrew. This estimate, like all others, is not standardized, and different groups and individuals compiled their own, unique loss estimates from Hurricane Andrew. There is a range of loss estimates following a disaster, but no official estimate (or official scorekeeper). The lack of a consistent framework for loss estimation makes it difficult to accurately compare the losses of natural disaster events to one another. For example, did Hurricane Georges actually cause less damage than Hurricane Hugo or was the loss estimation framework simply different? And of the varying estimates of losses, which one is to be consistently used? Clearly, the lack of a standard framework makes it extremely difficult to accurately identify trends in natural disaster losses (see Howe and Cochrane, 1993, for guidelines on the uniform measurement of economic damages from disasters). Moreover, this inability makes it more difficult for the federal government to identify which disaster mitigation policies represent the more cost-effective options.

TABLE 2–1. Current Dollar Estimates of $30 Billion in Damages Directly Related to Hurricane Andrew in South Florida.

Type of Loss	Amount (billions of dollars)	Sources and Notes
Common insured private property	16.5	Sheets, 1994; includes homes, mobile homes, commercial and industrial properties and their contents, boats, autos, farm equipment and structures, etc.
Uninsured homes	0.35	*Miami Herald*, 16 February 1993, reported in Rappaport, 1993.
Federal disaster package	6.5	Anderson et al., 1992; represents 90% of $7.2 billion package (the rest went to Louisiana).
Public infrastructure		
State	0.050	Filkins, 1994; tax revenue shortfall.
County	0.287	Rappaport, 1993.
City	0.060	Tanfani, 1992; Miami only.
Schools	1.0	Rappaport, 1993.
Agriculture		
Damages	1.04	McNair, 1992a,b.
Lost sales	0.48	Fatsis, 1992.
Environment	2.124	Rappaport, 1993; includes state request for cleanup and repair of parks, marinas, beaches, and reefs.
Aircraft	0.02	Rappaport, 1993.
Food claims	0.096	FEMA Flood Insurance Administration, reported in Rappaport, 1993.
Red Cross	0.070	Swenson, 1993.
Defense Department	1.412	GAO, 1993; for DOE and USACE expenses during recovery.

SOURCE: Pielke, 1995.

In an effort to help standardize the data used in estimating the direct losses in natural disasters, we suggest the framework shown in Table 2-2. This table could be refined by distributing it to parties affected by disasters and asking them for input regarding additional items to be included. If used consistently, this framework should allow the federal government to begin to compile more consistent loss estimates, better understand trends in losses, and ultimately provide a basis for better decisions in hazard mitigation policy.

The committee recommends that this framework be applied to all of the various types of hazards identified earlier in this chapter. In compiling data for loss estimates, it is generally recommended that losses be calculated as the cost required to restore buildings and structures to their pre-disaster condition. Different hazards naturally affect structures, infrastructure, and people differently. Use of the framework proposed in Table 2-2 should promote a more systematic compilation of the types of losses associated with different disasters.

TABLE 2-2 Sample Data on Direct Impacts per Each "Major" Event (dollar amounts should be entered in each cell in the table, except for human losses)

Who Initially Bears The Loss					
Type of Loss	**Insurers**	Government[a]	**Business**	Individuals	NGO
Property:					
Government					
Structures					
Contents					
Business					
Structures					
Contents					
Residential					
Structures					
Contents					
Landscapes					
Autos, boats and planes					
Infrastructure:					
Utilities					
Transportation					
Agricultural products:					
Crops					
Livestock					
Human losses:					
Deaths					
Injuries					
Cleanup and response costs[b]					
Adjustment costs, temporary living aid[c]					

NOTE: If possible, direct primary and secondary losses should be tabulated separately.

[a] Ideally, losses of federal, state, and local and tribal governments should be separately collected and recorded.

[b] Includes costs of added police protection immediately after the event.

[c] Includes expenditures of charities such as the Red Cross.

RECOMMENDATIONS

We recommend the following steps be taken:

RECOMMENDATION 2-1: One agency of the federal government should be made responsible for compiling a comprehensive data base containing the losses of natural disasters, adhering to the structure outlined in Table 2-2 wherever it is feasible. The committee believes that the Bureau of Economic Analysis (BEA) within the U.S. Department of Commerce, in consultation with FEMA and other federal agencies involved in natural disaster preparedness, response, and mitigation activities, is best suited for this purpose.

The U.S. Department of Commerce is a logical agency to carry out this assignment because two of its major components already have related responsibilities: the National Weather Service compiles loss estimates for all weather-related disasters and the Bureau of Economic Analysis regularly compiles and reports data on the nation's economic performance, an activity closely related to collecting and reporting data on the economic impacts of natural disasters. Along with the Census Bureau and STAT-USA, BEA is part of the Commerce Department's Economics and Statistics Administration. BEA's mission is to produce and disseminate accurate, timely, and relevant statistics that provide government, businesses, households, and individuals with a comprehensive, up-to-date picture of economic activity. BEA's national, regional, and international economic accounts present basic information on key issues such as U.S. economic growth, regional economic development, and the nation's position in the world economy. The BEA develops its figures of economic performance in a setting relatively free of political bias and vested interests. For all these reasons, it appears to be the agency most capable of compiling consistent disaster loss estimates to the nation.

In compiling its loss estimates on earthquakes in particular, the U.S. Department of Commerce should draw on the data supplied by state, local, and regional governments that use the HAZUS (Hazards, U.S.) earthquake loss estimation tools developed by the National Institute of Building Sciences for FEMA (see Box 2-1). The data bases, tools (e.g., GIS), and engineering and technical knowledge used in the HAZUS model for earthquake loss estimation appear to be applicable to estimating losses from major hurricanes. As such, Commerce should explore with FEMA the prospects for extending the HAZUS model to cover loss estimation from major hurricanes.

The U.S. Department of Commerce might also find it useful to solicit comments on Table 2-2 and specifically should request interested parties to identify types of loss data that could be collected at reasonable cost following a major disaster. Similarly, the U.S. Department of Commerce could make use of simulation models such as the HAZUS model used by FEMA (see Box 2-1).

It is worth noting that a program for the collection of accurate natural disaster loss data must proceed on various time scales. That is, some post disaster information tends to dissipate rapidly, requiring a rapid response with professional expertise. Other loss information can take a long time to stabilize, requiring a long-term commitment to data collection.

Finally, any agency charged with the additional data collection responsibilities recommended here should be given an appropriate level of resources to do the job effectively.

BOX 2-1

DESCRIPTION OF THE HAZUS LOSS ESTIMATION METHODOLOGY

FEMA and the National Institute of Building Safety (NIBS) have developed an earthquake loss estimation methodology entitled HAZUS (Hazards, U.S.). This software program was developed to help provide a standardized methodology for estimating the losses associated with earthquakes. FEMA began work on HAZUS in October 1992 and released the program in the spring of 1997.

HAZUS uses mathematical formulas and information about building stock, local geology and the location and size of potential earthquakes, economic data, and other information to estimate losses from potential earthquakes. HAZUS a geographic information system (GIS) to map and display ground shaking the patterns of building damage, and local demographic information. Given a hypothetical earthquake event, HAZUS estimates (among other things) the violence of ground shaking, the number of buildings damaged, the number of casualties, and the estimated cost of repairing projected damage and other effects. Not only can HAZUS be used to estimate local impacts, it can be used to compare seismic risks across regions throughout the continental United States.

HAZUS aims to provide local, state, and regional officials information to plan for earthquakes, mitigate against future losses, and prepare for emergency response and recovery. In addition, HAZUS may be used to prepare a quick loss estimate following an earthquake or to provide the basis to assess the nationwide risk of losses from earthquakes.

RECOMMENDATION 2-2: The agency charged with the overall data collection should obtain insured paid claims data from available sources, such as PCS and IBHS.

In addition, the agency should work with relevant trade associations, especially the National Association of Insurance Commissioners (NAIC), to obtain any additional data that may be useful. The NAIC could be instrumental in achieving consensus among state regulators to induce regulated insurance companies to provide the appropriate data. The agency charged with data collection should do its best to avoid double counting losses reported by different sources.

RECOMMENDATION 2-3: The agency charged with data collection responsibilities must also strive to collect data on losses incurred by uninsured individuals, businesses, and governments that are not otherwise reimbursed by disaster aid from some other level of government (typically the federal government).

Several avenues for estimating the disaster losses absorbed by the uninsured should be explored, including: (1) post-event sampling (for very large disasters); (2) extrapolations from other data bases, such as the data compiled by the SBA from loan applicants who presumably are not insured or not well-insured; (3) data compiled by insurers and commercial sources of insurance data (such as PCS) that may indicate the amounts of deductibles absorbed by individuals and businesses who do receive insurance payments; and (4) extrapolations from insured claims data.

RECOMMENDATION 2-4: The federal agency charged with the overall data collection effort should encourage and work with states and localities to collect disaster-related data.

Such data need not be reported to the federal government after every disaster but could be reported annually. Congress could amend the Stafford Act to require such reporting as a condition for states and localities to receive federal disaster aid in the future, although such a requirement could be viewed as an unfunded mandate and thus subject to further analysis before being implemented. In addition, it is not clear if the federal government has the legal authority to audit any cost data submitted by the states and localities.[14] This hurdle might be overcome, however, if the National Emergency Management Association (NEMA) developed ways to collect the data from the individual states. FEMA should work with NEMA to bring this result about.

[14] States and localities are already required by the Stafford Act to submit estimates of damage immediately following an event for which they seek a presidential disaster declaration. These estimates, however, are necessarily based on the very limited data that are available at the time of such an event. The recommendation outlined above calling for annual reporting would require these jurisdictions to assemble more complete and accurate costs, at least for the expenditures they make on account of all disasters, including events that may not qualify for a presidential declaration but that nevertheless fit the definition set by the federal government for purposes of its comprehensive data collection program.

RECOMMENDATION 2-5: The Office of Management and Budget, in consultation with FEMA, should develop annual, comprehensive estimates of the payouts for all disaster costs incurred by federal agencies.

As outlined above, these costs at the very least should be broken down into four categories: compensation payments to individuals and businesses (including the estimated subsidy cost of any loans designed to help cover disaster-related expenses); response costs; losses to government-owned infrastructure (including both state and local costs that are reimbursed by the federal government and damage to federally owned facilities and property); and payouts from federal insurance programs (with annual premium receipts being shown separately). It would also be useful if the data in each category were disaggregated by type of event and loss (such as losses to buildings, other infrastructure, and compensation for lost income, in the case of disaster-related unemployment insurance payments). Furthermore, to provide some perspective on current and future loss estimates, it would be extremely helpful if these data were assembled for some historical period. The results could be published in OMB's *Analytical Perspectives* that accompanies the annual budget.

To carry out such an exercise it would be necessary for OMB (working with FEMA and the federal agency charged with the more comprehensive data collection effort) to develop a standardized definition of what events to include in the data base. One obvious defining characteristic could be dollar loss above a certain threshold, as determined by a preliminary assessment of direct losses (for example, by using loss estimation models such as HAZUS). In this connection, the relevant agencies should explore with organizations that currently maintain insurance claims data the feasibility of using different dollar cost thresholds than the ones they may currently be using (such as the $25 million per-event threshold now employed by PCS) for purposes of determining which events should be included in the data base. It may also be appropriate to add human losses to the defining criteria.[15]

The committee recognizes that because it may not be possible, or practical in light of the costs, to require all agencies immediately to work with a standardized definition. Accordingly, the use of any agreed upon definition should be phased in over some reasonable period. Once the standard becomes effective, it should not be costly for agencies to organize their data around it. If modest resources were appropriated, it would also be useful for the agencies to reorganize their historical cost data to be consistent, to the extent possible, with the new definitions so policymakers would have sufficient data from the past to make long-term projections.

[15] The Stafford Act does not provide clear and objective criteria for establishing an appropriate threshold, however.

RECOMMENDATION 2-6: An effort should be made to collect loss data for direct primary and secondary losses separately.

Secondary losses can be significantly affected by the availability and effectiveness of emergency response measures. Separate data on secondary losses can help policymakers to assess existing response measures, in design and in practice, and to develop improvements in the future.

3

Indirect Losses of Natural Disasters

INTRODUCTION

Indirect losses of natural disasters, or losses resulting from the consequences of physical destruction, have not been measured, studied, and modeled to the same extent as direct losses (the monetized losses of physical destruction). Recent unprecedented business interruption losses—$6.5 billion in Northridge (Gordon and Richardson, 1995) and a staggering $100 billion of interruption losses in the 1995 Kobe earthquake—have focused attention on the need for more intensive scientific study and measurement of these indirect losses. Evidence to date suggests that the proportion of indirect impacts increases in larger disasters, and thus may constitute a larger fraction of total losses and damage in large disasters than in smaller disasters (Gordon and Richardson, 1995 and Toyoda, 1997).

By their nature, indirect losses are harder to measure than losses stemming directly from physical damage. For example, a ruptured power line is readily observed and the cost of its repair evaluated. Far less obvious are losses such as those of industries that are forced to close down because they lack critical power supplies, firms with power that lose business because suppliers or buyers lacked power, and firms that lose business because employees of firms affected by the power outage have reduced incomes and consequently spent less. Compared to a natural disaster's direct effects, indirect losses are more difficult to identify and measure, and are generally spread over a much wider area.

Additionally, there are almost no programs or processes in place to draw upon in measuring indirect losses. Two exceptions to this observation are business interruption insurance and unemployment insurance. The usefulness of these data are limited, as many firms do not carry business interruption insurance, and that many indirect effects may not qualify for reimbursement under such insurance. Similarly, unemployment insurance data do not adequately reflect employment and income losses that may occur in the wake of a natural disaster. For many, proving eligibility can be troublesome; for others, the key impact is not unemployment per se but reduced work and income that does not qualify for program assistance. In both situations, the coverage problem is exacerbated by the complexity of extracting the information from existing sources. Business interruption reimbursements may be lumped with other types of insurance payments. In the case of unemployment insurance, it may be difficult to separate claims attributable to the disaster and claims that would have arisen as a consequence of typical business and economic cycles.

Some beachfront property became uninhabitable due to damage from Hurricane Fran in 1996. (Photo courtesy of FEMA.)

Limited available sources of data and the often high cost of primary data collection have led to attempts to measure indirect losses using statistical models of the type that have long been utilized for economic forecasting and economic impact analysis. A modeling approach is also potentially able to project expected future outcomes over a period of years, and estimate indirect losses associated with a particular actual event. The forward-looking capability is critical for developing simulation models for planning mitigation and emergency responses.

Recent studies evaluating model-based estimates suggest that the models designed for traditional economic forecasting and impact analysis do not accurately estimate indirect effects that occur in the wake of a natural disaster. These models must be substantially revised in order to be reliable in estimating indirect effects. Prospects of their long-run cost-effectiveness compared with primary data collection helps justify the research and testing necessary to make the needed revisions.

This chapter identifies types of indirect effects and critiques current methods of measuring indirect losses, particularly existing modeling methodologies. It also describes ways in which models can be more usefully employed to generate reasonable estimates of indirect losses. Our recommendations cumulatively constitute an agenda that addresses the current lack of information on indirect effects of natural disasters. As we believe that the Bureau of Economic Analysis could best assume responsibility for the collection of data on direct losses, we conclude that the BEA should also be charged with implementing the recommendations outlined in this chapter. Many of these recommendations call for new studies, surveys, and research. Our knowledge of the losses exacted by natural disasters in the United States is fragmented and woefully incomplete. If significant strides are to be made in reducing those losses, sufficient funding will be required to support the studies and research described in this report.

TYPES OF INDIRECT LOSSES

In the short-term, disasters can produce indirect losses and gains. Losses include:

- Induced losses in sales, wages, and/or profits due to loss of function. The inability to operate may derive from either direct physical damage to commercial structures or from infrastructure failure.
- Input/output losses to firms forward-linked or backward-linked in production to businesses closed as a result of direct physical damage or infrastructure failure. Slowdowns or shutdowns are induced by reductions in demands for inputs and supplies of outputs from damaged firms.
- Spending reductions from the income losses triggered by firm closures or cutbacks—so-called multiplier, or ripple, effects. Employees of the firms experiencing reduced production and sales suffer income losses and subsequently curtail their own expenditures, initiating a new round of firm cutbacks.

In addition, disasters may generate short-term gains from:

- Changes in future production, employment, and income and/or changes in these flows outside the damaged area (and the ripple effects thereof). Current production outside the immediate area of impact or future production within the affected region may compensate for initial disaster-induced losses.
- Income gains outside the impact area to owners of commodities inflated in price by disaster-induced shortages. Both agricultural commodities lost in a disaster and construction materials demanded during reconstruction are particularly likely to generate these windfall profits outside the region.
- Positive economic stimuli of jobs and production generated from cleaning up and rebuilding and the multiplier effect of those increases.

Disasters also have longer-term indirect impacts: altered migration flows, changes in development and housing values resulting from changes in insurance costs, reduced consumption (if borrowing occurred to repair and replace damaged structures and goods), and altered government expenditures that derive from new patterns of migration and development.

From a very broad temporal and spatial perspective, the *net* indirect economic impacts of disasters may be zero[1]. Though, this may seem counter-intuitive, measured over the entire economy, the negative and positive effects may cancel out. Still, precisely because the winners and losers are different groups of individuals and businesses, redistributional indirect impacts of disasters are *not* zero.

These are three key reasons for identifying and measuring indirect impacts of disasters: (1) to inform plans for assistance to disaster victims; (2) to value mitigation measures; and, (3) to plan emergency response programs. Indirect losses of concern to (1) and (3) are losses that occur in the immediate region of impact near the time of the event. To the extent that mitigation costs are to be borne primarily by persons and firms in the immediate area of potential impact, then *region-specific* net loss savings are the pertinent impacts. Even if the mitigation is federally funded, region-specific savings may still be more relevant than total savings. Assuming federal aid to immediate victims continues, there is a legitimate societal interest in preventing those immediate losses. The valuation of mitigation measures should logically include long-run regional impacts (like the delayed responses to nationwide drought in the 1930s and 1950s), but the substantial passage of time between disaster and impact renders measurement of these phenomena particularly formidable.

RECOMMENDATION 3–1: Measurement, study and modeling of indirect losses of natural disasters should concentrate on those losses that occur in the region of impact near the time of the event. The geographic boundaries and the time horizon over which the measurement of indirect losses should occur need to be defined and standardized.

The remainder of this chapter expands upon certain themes included in Recommendation 3–1.

CURRENT METHODS OF MEASURING INDIRECT LOSSES

Two methods of *ex post* measurement of indirect flow losses have been identified by Brookshire et al. (1997). The first relies upon surveys of businesses and households (primary data), and the second utilizes secondary data such as

[1] More detailed descriptions of types of indirect flow impacts and examples of offsetting effects are presented in West, 1996.

tabulations of insurance claims, small business loans, and other forms of disaster relief. In fact, however, there are no mechanisms to systematically ensure that surveys are conducted, nor is there a standard survey format. As a result, no data base exists that would allow the calibration of sophisticated simulation models of indirect losses to study low-probability events with potentially very large indirect losses. The lack of such a data base has in turn inhibited development of simple, rule-of-thumb relationships that might permit efficient estimation of indirect losses for many purposes.

RECOMMENDATION 3-2: The agency charged with collecting the direct loss data should commission surveys for the collection of detailed indirect economic loss data from recent disasters, and establish a program for consistently collecting such data on future disasters until a secondary methodology for "standard" disasters can be validated (see Recommendation 3-3). Once an adequate indirect loss data base is established, such survey data should be collected for all future disasters that have initial total losses (based on model projections) that exceed $10 billion (in 1998 dollars).

Because survey data collection is relatively expensive, even when the survey has a narrowly limited time and location, it would be desirable to develop a method based on secondary data to use in *ex post* estimation of indirect losses for most natural disasters. Initially, however, it is necessary to build a data bank of estimated losses from primary survey data to validate the indirect methods. Once an adequate data base has been established, continued surveys of major events are essential to better understand the significance of indirect losses in larger disasters.

RECOMMENDATION 3-3: A study to validate alternative techniques for estimating indirect losses from secondary data should be conducted. This study would test proposed methods using the primary survey data collected pursuant to Recommendation 3-2.

Recommendations 3-2 and 3-3 address necessary measurement of indirect losses after natural disasters. However, *ex post* measurement by itself does not directly address the three primary purposes noted above for quantifying indirect effects. Determining appropriate amounts of resources for victims of disasters cannot wait until after a disaster (when a survey might be conducted). Valuing mitigation requires estimation of expected loss savings over time. Measurement of actual losses from one particular event contributes only limited information for that purpose. Finally, planning emergency response necessarily must precede a disaster.

These *ex ante* approaches require a modeling methodology that permits forecasting (or simulation) of indirect losses. Standard regional economic forecasting or impact models have been used to "predict" indirect losses of natural disasters. These include input-output (I-O) impact models (e.g., Rose and Benavides, 1997; NIBS, 1997; Boisevert, 1992; Cochrane, 1997), computable general equilibrium models (Brookshire and McKee, 1992; Boisevert, 1995), and simultaneous equation econometric models (Ellison et al., 1984; Guimares et al., 1993; West and Lenze, 1994).

The evidence to date suggests that such models appear to overstate both indirect regional economic losses from natural disasters and indirect regional economic gains from reconstruction. For example, using historical analogies to other earthquakes, Kimbell and Bolton (1994) estimated that reconstruction following the Northridge earthquake would add 20,000 jobs to the Los Angeles economy over four quarters. This estimate is far below the 270,000 job gain predicted by Cochrane et al. (1996) for the entire rebuilding period (i.e., approximately 3 years) using an input-output methodology. Actual data for the Los Angeles area following the earthquake are not consistent with such a large positive impact (Bolton and Kimbell, 1995). Similarly, West (1996), analyzed regional econometric model simulations of the impact of Hurricane Andrew published in West and Lenze (1994) and concluded they were clearly too high, not by a whole order of magnitude, but perhaps by 70 to 85 percent.

The core of the problem with statistically based regional models is that the historical relationships embodied in these models are likely to be disrupted in a natural disaster. Temporary or emergency measures taken after disasters are not characteristic of usual socioeconomic conditions, and are therefore not reflected in the model. Economic resiliency can be expected from changes in historical regional production functions, changes in historical purchase and sale patterns, temporary reassignment of labor from outside the area, increased overtime of labor in shortage, and temporary housing arrangements (such as doubling up with relatives or residing in a hotel).

In short, regional economic models have been developed over time primarily to forecast future economic conditions or to estimate the effects of a permanent change (e.g., the opening or closing of a manufacturing plant). The abruptness, impermanence, and often unprecedented intensity of a natural disaster does not fit the event pattern upon which most regional economic models are based. The models are thus inappropriate for simulating natural disaster losses. There has been relatively little analysis on how to modify these models in order to increase their accuracy for disaster loss analysis. Secondary regional data currently available on sales, employment, wages, and income following natural disasters provide an opportunity to test possible model modifications, but this testing has not been systematically undertaken.

RECOMMENDATION 3-4: A study to test regional economic model modifications for disaster loss analysis should be conducted. Such a study would utilize secondary regional data currently available on sales, employment, wages, and income following natural disasters.

This recommendation focuses on efficiently using currently available secondary data, a critical first round of work that logically precedes collection of new primary data for supporting such model-based approaches.

OPTIMAL METHODS FOR MEASURING INDIRECT ECONOMIC FLOW EFFECTS

The study suggested in Recommendation 3-4 would provide an important component of a model system for measuring indirect economic flow effects. But to use such a model for planning emergency response and valuing mitigation activities, one needs a microsimulation model to generate a timeline of regional commercial/industrial closures (or cutbacks) that trigger indirect losses. A microsimulation model simulates the behavior of individual units, such as businesses or households. It contains a set of rules that define the behavior of each unit (the rules may be probabilistic). The model provides information on an exogenous event (such as a natural disaster), allows the individual units to respond, and then aggregates the results from those units to estimate the impacts on the economy, the market, or industries and businesses. The model may also provide iterative feedback to the individual units.

The type of microsimulation model we envision, focused on specific buildings and structures, has five major components:

1. a regional data base;
2. an event-to-loss mapping capability;
3. an emergency infrastructure repair response algorithm;
4. a private commercial/industrial repair response algorithm; and
5. a residential reconstruction algorithm.

Data and techniques available for developing these five components differ, and the need to fill in critical information and methodological gaps leads to the remaining recommendations of this section.

The first component of the suggested microsimulation model, a regional data base, should contain a fully geocoded inventory of structures and infrastructure capable of identifying commercial/industrial closures from specific structure and lifeline (roads, water, and electricity) losses. Critical documented aspects of each structure include: typical input-output linkages to the regional economy; potential substitutes from outside the regional economy for traditional regional input-output linkages; infrastructure critical and feasible for bringing employees to work; in the case of retailing and service establishments, infrastructure critical and feasible for bringing customers to other places of business; numbers of employees and wages of employee; and profit income in the region.

Much of the data on firm location, employment, and wages are currently available from reports already required by the federal-state cooperative program on unemployment insurance. Considerable study has also been done on modeling building and lifeline performance in natural disasters. The missing links are how lifeline losses and building losses determine closures. Kiremidjian et al. (1997) estimated the effects of water system loss on Palo Alto, California, for two scenario events. These studies illustrate the importance of lifeline availability for economic functionality, but there are no comprehensive models that systematically relate these phenomena. Similarly lacking is research on the role of building damage in determining indirect losses.

Some survey data on lifeline resiliency have been collected. Several years ago, the Disaster Research Center (DRC) of the University of Delaware conducted an extensive survey of businesses in the Memphis region. Specific questions were asked regarding the degree of dependency on different lifeline services and the amount of time that each business could operate without full service. This information needs to be extended beyond lifelines and to other parts of the United States to better understand regional resiliency to natural disasters.

RECOMMENDATION 3-5: A range of businesses in different regions of the United States should be surveyed to determine their resiliency to: (1) physical building damage (including feasibility of short-term relocation); (2) loss of infrastructure and utilities (roads, bridges, electricity, water, gas), and; (3) loss of traditional suppliers and markets. Results should be verified by statistical methods (to examine consistency of results by nature of business and size of business) and engineering methods (to determine process-determined lifeline needs).

Such a survey is critical if existing models of physical damages for determining indirect losses are to be effective. Accurate estimation of indirect losses requires clear knowledge of the levels of direct damage and business resiliency.

We now consider the remaining features of the suggested microsimulation model. The second module would ideally determine which commercial/industrial closures will occur due to direct damage to buildings, loss of lifelines to businesses, and loss of lifelines critical for transporting employees and/or customers. The model's third element would determine how long these losses of functionality occur. This depends on the timeline for infrastructure repair. The fourth part of the model characterizes private commercial/industrial repair response.

Repair time is critical to implementing the ideal model's third and fourth modules (Chang et al., 1996; Shinozuka et al., 1997; Shinozuka et al., 1998). However, this parameter is one of the more uncertain parameters in the modeling process. There are many ways in which a damaged lifeline can be repaired.

Thus, in the best cases outages may last only a few minutes or hours (Lopez et al., 1994); but in the worst, interruptions can last several months, as after the 1995 Kobe earthquake (Takada and Ueno, 1995). Experience teaches us that such losses are initially, primarily a function of restoration time, but then tend to increase exponentially as restoration time is extended.

Similarly, there are very limited data on length of time to recover full use of a commercial/industrial building. The Applied Technology Council (1985) provides heuristic estimates used in NIBS (1997) and Kiremidjian et al. (1997). However, there are no formal simulation models of restoration that parallel simulation models of physical damage. Restoration depends not just on physical damage but also on the capacity of the construction industry and the ability to move needed materials and labor to the disaster area.

RECOMMENDATION 3-6: A formal restoration model that utilizes available technical and economic data and is consistent with observations from actual natural disasters should be developed.

Development of such a model may well uncover additional data needs. These likely would relate to physical and economic aspects of the construction industry and could be incorporated into questionnaires for existing surveys of construction firms.

The second, third, and fourth modules of the suggested microsimulation model jointly determine a timeline of regional commercial/industrial closures (or cutbacks) that trigger indirect losses. Wage and profit income lost from closures are estimated from data in the regional data base. Broader measurement of indirect losses must also include a fifth component, residential reconstruction. This module translates damage to residential structures into a reconstruction/rebuilding profile, which depends upon: (1) residential damage; (2) available funds for rebuilding; (3) any "Jacuzzi®" effects (enhancing the original structure beyond reconstruction); and, (4) decisions to abandon totally destroyed structures and migrate from the region.

Given income and reconstruction flows simulated in the microsimulation model, the modified regional impact model can be used to simulate multiplier or ripple effects. Given an actual disaster, the system can forecast indirect losses for purposes of planning regional aid. Equally important, it should be used in the context of a probability distribution of disasters to evaluate mitigation proposals and to improve the efficiency of emergency response efforts.

RECOMMENDATION 3-7: Research should be conducted on linking a comprehensive indirect loss model to a probabilistic physical damage catastrophe model, for purposes of evaluating mitigation and improving the efficiency of emergency response programs.

In sum, the recommendations outlined in this chapter suggest a mix of primary data collection, more intensive use of available secondary data, and development of new modeling techniques that will permit significant, cost-effective improvement in measurement and prediction of indirect losses.

4

Conclusions and Recommendations

This report has explained the gaps in our knowledge of natural disaster losses and why these gaps should be filled. Poor knowledge of the resulting economic losses hinders implementation of effective disaster mitigation policies and emergency response programs. Better loss estimates would benefit federal, state, and local governments, insurers, scientists and researchers, and private citizens (both as taxpayers and insurance purchasers).

It is clear that data on economic losses of natural disasters to the nation are incomplete and spread widely across the public and private sectors. Information on both direct and indirect costs is lacking. If data on uninsured direct losses are limited, our understanding of indirect losses is even more incomplete. These indirect losses are clearly difficult to identify and measure. However, in large disasters they may be significant and, within the immediately affected regions, potentially greater than the direct losses due to physical destruction, especially in large disasters.

LOSSES VERSUS COSTS

In generating a national indicator of disaster damage, the focus should be upon the *losses* resulting from disasters, rather than *costs.* Losses encompass a broader set of damages than costs. Losses include direct physical destruction to property, infrastructure, and crops, plus indirect losses that are the consequence of disasters, such as temporary unemployment and lost business. Costs typically refer only to cash payouts from insurers and governments. The term "losses," as defined above, better portrays the true economic impacts of disasters.

DIRECT LOSSES: DATA COLLECTION, REPORTING, AND AGENCY AND ORGANIZATIONAL ROLES

One step toward producing more complete loss estimates would be to assign one agency of the federal government to compile a comprehensive data base identifying the direct costs of natural disasters, as well as the individuals and groups who bear these costs. These data should be collected according to the framework described in Chapter 2, for each natural disaster exceeding a given dollar loss threshold. The U.S. Department of Commerce's Bureau of Economic Analysis appears to have the capabilities to compile such a data base, with considerable input and assistance from FEMA and other relevant federal agencies. Whatever agency is selected should be given sufficient resources to accomplish this assignment.

The recommended loss estimate data base would be compiled from many sources, including organizations such as Property Claims Services and the Institute for Business and Home Safety (which compile data on paid insurance claims) and other federal, state, and local agencies. The assistance of relevant professional associations, such as the National Association of Insurance Commissioners, should be enlisted to obtain other relevant data. A synthesis report containing data on disaster losses should be published periodically, preferably annually. One way the federal government might make sure it receives at least the state and local data is by amending the Stafford Act, requiring the data to be submitted as a condition for future federal disaster aid.

A related recommendation is for the federal Office of Management and Budget, with advice from FEMA, to develop annual, comprehensive estimates of the payouts for the direct losses (due directly physical damage) made by federal agencies. These data should be divided into at least four categories:

1. compensation payments to individuals and businesses (including subsidies on loans to help cover disaster-related expenses);
2. response costs;
3. losses to government-owned infrastructure (including state and local costs that are reimbursed by the federal government); and,
4. payouts from federal disaster insurance programs (with annual premiums shown separately).

These data should be assembled for some historic period in order to provide information of trends of disaster losses and payouts. Such an effort is critical if the federal government and policymakers are to better plan for future disaster-related expenditures, including mitigation programs and activities.

The largest current gap in direct loss data involves uninsured losses borne by businesses and individuals. These data might be obtained through post-event sampling (in large disasters) and extrapolating these losses from other data bases. Data from loan applicants to the SBA's disaster relief program or data from insurers like PCS would indicate the deductibles paid by insured businesses and individuals.

INDIRECT LOSSES: MODELING THE LOSSES AND CONSTRUCTING A LOSS DATA BASE

Indirect losses in natural disasters stem from the consequences of physical damage (direct losses). Physical damages in disasters typically initiate events that alter economic flows. Businesses may be disrupted after a disaster due to damaged infrastructure (power, water, transportation, communications), and many workers may be temporarily unemployed. These indirect losses have not been studied or measured as closely as direct losses, largely because they are notoriously difficult to identify and accurately measure.

Due to the limited sources of indirect loss data, statistical models are often used to compile indirect loss estimates. Though these models may help address problems due to a lack of available data, they must become more reliable if they are to be used as guides in setting mitigation and other hazard-related policies.

If this is to occur, however, accurate, firsthand (primary) data on indirect losses must be available for model calibration and validation. The recommended data collection and coordination program should thus also include surveys for the collection of detailed primary data on indirect economic losses from recent disasters (again, sufficient resources for this effort must be budgeted). Once a sufficiently reliable data base of these indirect losses has been generated, the agency should continue to collect indirect loss data on large disasters—those with model estimates of greater than $10 billion in losses. While the indirect loss data base is being constructed, efforts toward more effective uses of secondary data (data generated for purposes other than indirect loss estimation, such as unemployment insurance payouts) should be continued. We thus recommend that an assessment of methods for estimating indirect losses with secondary data be conducted.

It is important to understand the timing of economic disruptions that trigger indirect losses in order to plan for efficient emergency responses and to assess the cost-effectiveness of alternate mitigation strategies. The committee recommends that a microsimulation model be developed to create a timeline of regional commercial and industrial closures. Other models that should be devised include a formal restoration model and a comprehensive indirect loss model.

MOVING TOWARD BETTER KNOWLEDGE OF DISASTER LOSSES

The lack of accurate information on these losses is a barrier to more effective hazard mitigation. As a step toward improving mitigation programs, efforts at centralizing these data and compiling better loss estimates must be strengthened. The federal government and private sector should combine their knowledge and data in providing better estimates of direct losses. The federal government must mount and back a significant data collection and research effort if better estimates of losses due to disasters are to be compiled, especially indirect losses. With a strong commitment, this could be accomplished within the next ten years. Until relatively accurate estimates are available, the true economic losses in natural disasters will remain poorly understood and the benefits of disaster mitigation activities only imprecisely evaluated.

References

Anderson, P.G. Lim and M. Merzer. 1992. Chiles seeks $9 billion in aid, Bush will urge $7.2 billion package. The Miami Herald. Sept. 9.

Applied Technology Council (ATC). 1985. Earthquake Damage Evaluation Data for California. ATC-13. Redwood City, Calif.: ATC.

Boisevert, R. 1992. Indirect losses from a catastrophic earthquake and the local, regional, and national interest. *In* Indirect Economic Consequences of a Catastrophic Earthquake. Washington, D.C.: FEMA, National Earthquake Hazard Reduction Program.

Boisevert, R. 1995. Computable General Equilibrium Modeling for Earthquake Impact Analysis. Report to the Federal Emergency Management Agency. Ithaca, N.Y.: Cornell University.

Bolton, N., and L. Kimbell. 1995. The Economic and Demographic Impact of the Northridge Earthquake. Paper presented at the annual meeting of the Population Association of America.

Brookshire, D.S. and M. McKee. 1992. Other indirect costs and losses from earthquakes: issues and estimation. *In* Indirect Economic Consequences of a Catastrophic Earthquake. Washington, D.C.: FEMA, National Earthquake Hazards Reduction Program.

Brookshire, D.S., S.E. Chang, H. Cochrane, R.A. Oslon, A. Rose, and J. Steenson. 1997. Direct and indirect economic losses from earthquake damage. Earthquake Spectra. 13(4).

Chang, S., H. Seligson, and R. Eguchi. 1996. Estimation of Economic Impact of Multiple Lifeline Disruption: Memphis Light, Gas, and Case Study. Technical Report No. NCEER96-0011. Buffalo, N.Y.: National Center for Earthquake Engineering Research.

Changnon, S.A. 1996a. Impacts on transportation systems: stalled busses, blocked railroads, and closed highways. *In* The Great Flood of 1993, S. Changnon, ed. Boulder, Colo.: Westview Press.

Changnon, S.A. 1996b. Losers and winners: a summary of the flood's impacts. *In* The Great Flood of 1993, S. Changnon, ed. Boulder, Colo.: Westview Press.

Changnon, S., D. Changnon, E.R. Fosse, T. Hoganson, R.J. Roth, Sr., and J. Totsch,. 1997. Effects of recent weather extremes on the insurance industry: major implications for the atmospheric sciences . Bulletin of the American Meteorological Society 78:425–435.

Cochrane, H., B. Kling, D. Black, J. Schmehl, J. Curtsinger, J. Steenson. 1996. Indirect losses-real shocks and real dislocations. *In* The Economics of Natural Hazards. Partial draft, University of Colorado, Boulder.

Cochrane, H. 1997. Indirect economic losses. *In* Development of Standardized Earthquake Loss Estimation Methodology. Vol. II. Washington, D.C.: National Institute for Building Sciences.

Costanza, R., et al. 1997. The value of the world's ecosystem services and natural capital. Science 387: 253–259.

Eguchi, R.T., et al. 1998. Direct economic losses in the Northridge earthquake: a three-year perspective. Earthquake Spectra 14(2): 248.

Ellison, R., J.W. Milliman, and R.B. Roberts. 1984. Measuring the regional economic effects of earthquakes and earthquake predictions. Journal of Regional Science 24: 559–579.

Fatsis, S. 1992. Andrew reshapes S. Florida economy. The Miami Herald. September 8. Special section.

Federal Emergency Management Agency (FEMA). 1995 (December 6). National Mitigation Strategy: Partnerships for Building Safer Communities. Washington, D.C.: FEMA.

Federal Emergency Management Agency (FEMA). 1997 (March). Report on Costs and Benefits of Natural Hazard Mitigation. Washington, D.C.: FEMA.

Federal Emergency Management Agency (FEMA). 1998. Top Ten Major Disasters Ranked by FEMA Relief Costs. Fact Sheet. Office of Emergency Information and Public Affairs. Washington, D.C.: FEMA.

Filkins, D. 1994. Plan would raise most Dade tax bills, budget also proposes increased water fees. The Miami Herald. July 16.

Gordon, P. and H.W. Richardson. 1995. The Business Interruption Effects of the Northridge Earthquake, Research. Report No. LCRI–95–01R. Lusk Center Research Institute, School of Urban and Regional Planning, University of Southern California. April.

Guimares, P., F.L. Hefner, and D.P. Woodward. 1993. Wealth and income effects of natural disasters: an econometric analysis of Hurricane Hugo. Review of Regional Studies 23:97–114.

Howe, C.W., and H.C. Cochrane. 1993. Guidelines for the Uniform Definition, Identification, and Measurement of Economic Damages from Natural Hazard Events. Program on Environment and Behavior Special Publication No. 28. Boulder, Colo.: University of Colorado, Institute for Behavioral Science.

Insurance Information Institute (III). 1998. The Fact Book 1999: Property/Casualty Facts. New York: III.

Kimbell, L., and N. Bolton. 1994. The impact of the Northridge Earthquake on the economies of California and Los Angeles. Paper presented to the Seismic Safety Commission of the State of California, Burbank.

Kiremidjian, A., S. King, N. Basoz, K. Law, M. Vucetic, M. Doroudian, V. Iskandar, R. Olson, J. Eidinger, K. Goettel, and G. Horner. 1997. Methodologies for Evaluating the Socio-Economic Consequences of Large Earthquakes. The John B. Blume Earthquake Engineering Center, Dept. of Civil Engineering, Stanford University. Technical Report No. 126.

Kunreuther, H. and R.J. Roth, Sr., eds. 1998. Paying the Price: The Status and Role of Insurance Against Natural Disasters in the United States. Washington, D.C.: Joseph Henry Press.

Lopez, M., R. Tognazzini, and L. Minor. 1994. Impact of the 1994 Northridge Earthquake on the Los Angeles Electric System. Proceedings of the Joint New Zealand/U.S. Lifeline Workshop. Los Angeles, Calif. August 15–16.

Larson, Erik. 1998. Waiting for Hurricane X. Time 152(10):63–66. McNair, J. 1992a. Andrew's awesome impact. The Miami Herald. September 10.

McNair, J. 1992b. Study details hurricane's toll on local business. The Miami Herald. September 18.

National Institute of Building Sciences (NIBS). 1997. Development of A Standardized Earthquake Loss Estimation Methodology. HAZUS TM Technical Manual Vol. 1. Prepared for the Federal Emergency Management Agency. Washington, D.C.: NIBS.

Pasterick, E.R. 1998. The national flood insurance program. *In* Paying the Price: The Status and Role of Insurance Against Natural Disasters in the United States. H. Kunreuther and R. J. Roth, Sr., eds. Washington, D.C.: Joseph Henry Press.

Pielke, R.A., Jr. 1995. Hurricane Andrew in South Florida: Mesoscale Weather and Societal Responses. Boulder, Colo.: National Center for Atmospheric Research.

Pielke, R.A., Jr. 1997. Trends in Extreme Weather Impacts in the United States. Stanford, Calif.: Electric Power Research Institute.

Rappaport, E. 1993. Preliminary Report Hurricane Andrew 16–28, 1992 (updated March 2, 1993). Miami, Fla.: National Hurricane Center.

Rhinesmith, Alan. 1997. The federal budget and federal disaster assistance. Presentation before the Committee on Assessing the Costs of Natural Disasters of the National Research Council, December 15, 1997. Washington, D.C.

Riebsame, W.E., S.A. Changnon, and T. Karl. 1991. Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987–89 Drought. Boulder, Colo.: Westview Press.

Rojahn, C., S. King, R. Scholl, A. Kiremidjian, L. Reaveley, and R. Wilson. 1997. Earthquake Damage and Loss Estimation Methodology and Data for Salt Lake County, Utah (ATC-36). Earthquake Spectra 13:(4)623–642.

Rose, A. and J. Benavides. 1997. Inter-industry models for analyzing the economic impact of earthquakes and recovery policies: Illustrative examples [7/93; revised 11/93]. *In* Advances in Social Science Analysis of Earthquakes, B. Jones, ed. Buffalo, N.Y.: National Center for Earthquake Engineering Research.

Sheets, R. 1994. Statement before Hearing of the House Committee on Public Works and Transportation. H.R. 2873, The Natural Disaster Prevention Act of 1993. Subcommittee on Water Resources and Environment. February 2.

Shinozuka, M., A. Rose, and R. Eguchi. 1997. Engineering and Socioeconomic Analysis of Utility Lifelines. Buffalo, N.Y.: National Center for Earthquake Engineering Research.

Shinozuka, M., A. Rose, and R.T. Eguchi. 1998. Engineering and Socioeconomic Impacts of Earthquakes—An Analysis of Electricity Lifeline Disruptions in the New Madrid Area. Monograph Series; No. 2. Buffalo, N.Y.: Multidisciplinary Center for Earthquake Engineering Research.

Swenson, E.L. 1993. Testimony before the U.S. House of Representatives, Committee on Veterans Affairs. 103–4. Washington, D.C.: GPO.

Takada, S. and J. Ueno. 1995. Performance of Lifeline Systems during the 1995 Great Hanshin Earthquake. Proceedings of the 6th U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems. Osaka, Japan. July 18–19.

Tanfani, J. 1992. Miami tallies storm cost, may end up with net gain. The Miami Herald. September 11.

Toyoda, T. 1997. Economic Impacts and Recovery Process in the Case of the Great Hanshin Earthquake. Presentation to the Fifth U.S.-Japan Workshop on Urban Earthquake Hazard Reduction. Pasadena, Calif. January 15–17.

U.S. General Accounting Office. 1993. Disaster Management: Recent Disasters Demonstrate the Need to Improve the Nation's Response Strategy. Statement of J. Dexter Peach. Washington, D.C.: U.S. General Accounting Office. GAO/RCED-93–4. January 27.

West, C.T., and D.C. Lenze. 1994. Modeling the regional impact of natural disaster and recovery: a general framework and an application to Hurricane Andrew. International Regional Science Review 17:121–150.

West, C.T. 1996. Indirect economic impacts of natural disasters: policy implications of recent research and experience. Proceedings of Analyzing Economic Impacts and Recovery from Urban Earthquakes: Issues for Policy Makers. Conference presented by Earthquake Engineering Research Institute and Federal Emergency Management Agency, Pasadena, Calif.

Wright, J. 1996. Effects of the flood on national policy: some achievements, major challenges remain. *In* the Great Flood of 1993, S. Changnon, ed. Boulder, Colo.: Westview Press.

Appendix A

Environmental Impacts of Natural Disasters

It is recognized that many significant nonmarket effects result from natural disasters, including environmental impacts. Though our committee had a keen interest in these topics, it became clear that these impacts—though often significant—did not fit easily with this study's main report and conclusions for the following reasons: (1) not all disasters result in significant ecosystem impacts (e.g., many earthquakes have but minor impacts on ecosystems); (2) some extreme events have positive impacts on ecosystems (e.g., floods can help rejuvenate floodplain vegetation and are important drivers of many ecological processes in floodplains); and, (3) these impacts are mainly nonmarket and are exceptionally difficult to quantify and/or monetize. Though there are emerging efforts in quantifying and monetizing ecosystem services (e.g., Costanza, 1997), they are in their infancy and are not yet widely accepted.

Nonetheless, the magnitude of the environmental impacts of many disasters compelled the committee to discuss them and we do so in this Appendix. Though no specific recommendations regarding how environmental costs should be incorporated in loss estimates we provide here, we encourage policymakers in the relevant executive branch agencies to devote more attention and perhaps research to these issues. It is important in assessing environmental impacts to distinguish between impacts of disasters on the *natural environment* from those on the human-made *landscape environment.* As mentioned, events that societies label as natural "disasters" may also have beneficial ecological consequences. However, these benefits tend to only manifest themselves months or years after an extreme event (e.g., rejuvenation of a coniferous forest months and/or years after fires), or are often not readily apparent (e.g., recharging of groundwater stocks after a flood). These benefits to ecological systems are of course typically overshadowed by immediate, negative impacts on societies and structures; hence, the use of the term natural "disasters."[1]

[1] The committee has recommended that the direct costs of damages to landscapes be included in loss estimates. See Table 2-2.

BACKGROUND PRINCIPLES

Three principles apply to the assessment of the costs and benefits of extreme geophysical events to the nation's ecological systems. First, although the more tangible, quantifiable damages of extreme events to infrastructure and economies may be difficult to calculate precisely, the costs to and benefits for natural ecosystems—even from such apparently straightforward impacts as numbers of fish killed or trees destroyed—are even less tangible and may be nearly impossible to quantify precisely. Moreover, even if the physical effects can be measured, the monetary values of those impacts cannot be stated with precision.

Second, existing ecological systems have already adapted in many respects to the forces created by extreme events, such as floods or droughts. This process is lengthy, extending over thousands of years and involving the evolution of species and complex physical systems. The effects of geophysical extremes often are not undesirable. For example, major natural disturbances, such as fires or floods, rejuvenate old forests. The critical factors are the frequency, intensity, and extent of natural disturbances. If disturbances occur too frequently and over large areas, then only pioneering, short-lived, and opportunistic species survive. If disturbances occur too infrequently, then slower-growing, superior competitors for light, water, and nutrients replace the pioneers. Maximum diversity is maintained by an intermediate level of disturbance, so that patches of pioneers and superior competitors alike occur within the landscape. All of this suggests that attempts to eliminate natural disturbances (rather than attempts to mitigate their adverse impacts) can be counterproductive and in some cases, as in the 1927 and 1993 floods on the Mississippi River and the Yellowstone fires in 1988, can make a disaster worse.[2]

Third, precisely because many disasters are indeed "natural," they often produce mixed outcomes for the environment: benefits to some parts of the natural system and losses to others. For example, some thinning of tree branches caused by high winds or ice accumulations from winter storms can allow for subsequent stronger tree development, and studies of the 1993 flood in the Midwest revealed major ecological benefits in the immersed floodplains. To the average human observer, floodplain forests appear to change scarcely at all from year to year, and therefore the death of trees during or after a major flood seems

[2] The severe damage from the 1927 flood on the lower Mississippi River and in 1993 in the Upper Mississippi basin could have been substantially reduced if levees bordering the river had neither failed nor been overtopped, and if other forms of mitigation had been adopted. Meanwhile, the Yellowstone fires that occurred during the 1988 drought were worsened because of "let-it-burn" and other forest management practices and because fire prediction models at the time were outmoded and inadequate for such an extreme event (Riebsame et al., 1991).

catastrophic. However, the diversity of vegetation on the floodplain is a product of disturbances, such as major fires, droughts, and floods that occur very infrequently in terms of a human life span. Without droughts, floodplains would not get dry enough to burn, and fire-intolerant species would crowd out the wet prairies and trees. Even the most extreme geophysical events are thus not necessarily damaging to ecosystems, and in some circumstances can bring great benefits. Furthermore, the effects take months and years after the disturbance to assess, suggesting that immediate ecological or environmental accountings are prone to error.

Finally, as was outlined in the report, it is useful to assess the impacts of natural disasters by type of disasters. Because of their great spatial extent and longevity, major floods and droughts generally create the greatest environmental impacts, whereas earthquakes, hurricanes, thunderstorms, and winter storms cover less territory and their effects on the ecosystem are less pervasive and long-lasting. Below, we briefly review some case studies to illustrate the diverse environmental impacts of different categories of disasters, and the difficulties in precisely quantifying and monetizing these impacts.

FLOODS

Major floods create myriad effects on river-floodplain ecosystems. During periods of low flow, typically in midsummer, the rivers occupy channels. During rainy seasons, rivers spill into their floodplains, recharging the surrounding wetlands, forests, and lakes with fresh supplies of water, nutrients, and sediments. During great floods, floodplains do not merely store water, but become part of the flowing river itself, conveying water slowly downstream through the forests and marshes. Plant and animal species have adapted over time to exploit, tolerate, or escape seasonal floodpulses and exceptional great floods. The combination of the flood-adapted animals and plants, the seasonal flows and great floods, the river and its channels, and the complex patchwork of floodplain habitats constitute the dynamic and phenomenally productive river-floodplain ecosystem.

Large river-floodplain ecosystems provide valuable hydrological and ecological services and functions, such as flood storage and conveyance; the maintenance of biodiversity; retention, recycling, and conversion of potentially polluting nutrients into useful biomass; production of fish, wildlife, and forests; and the provisions of corridors for migratory fish and wildlife. Annual floodpulses help regulate and maintain these ecosystems by promoting exchanges of water, sediment, nutrients, and organisms between the rivers and their floodplains. Moreover, infrequent great floods and droughts help maintain habitat and species diversity (Sparks, 1996).

Flood of 1993. Though the record flood of 1993 in the Upper Midwest was an economic disaster, it was a boon to many plants and animals that lived in and along the Missouri and Upper Mississippi Rivers. Even the few species that appear to have been harmed by the flood, such as some trees, may benefit in the long term. Any harm that did occur may have been more the result of human factors rather than the flood itself, including failure of human-made levees, excessive loading of rivers and the Gulf of Mexico with herbicides and agricultural fertilizers, widespread dispersal of introduced pests, and the excessive drawdown of the Mississippi River after the flood.

It is not surprising that the flood of 1993 had both positive and negative effects on the river-floodplain ecosystems. Many mobile organisms have adapted to exploit such seasonal floods. For example, the flood benefited fish that spawned on the inundated floodplain, and wading birds in turn exploited the huge crop of young fish. In contrast, long-lived, stationary organisms, such as trees, were severely stressed or died as a result of the exceptionally long period of inundation. And yet the outcome for trees was not all bad. Many seedlings cannot germinate or grow in the shade of mature trees, so old forests were rejuvenated when mature trees died because of the 1993 flood.

Every component of the river-floodplain ecosystem, from the bottom to the top of the food chain, responded to the exceptional flood of 1993. At the shallow margins of the flood, nutrients were apparently released from newly flooded soils, stimulating phytoplankton. Aquatic insects likewise concentrated in the shallow water, perhaps consuming either the plankton or the remains of flooded terrestrial vegetation. Submergent aquatic plants grew in areas where the flood did not persist too long so they could reach sunlight. Where the flood rose higher and lasted longer, submersed aquatic plants virtually disappeared. About 52 species of fishes, representing 15 families, spawned on the floodplain during the flood (Maher, 1995). The abundant juvenile fish became food for larger fish and fish-eating birds, such as herons and egrets. The flood also took a heavy toll on trees, the longest-living organisms in the floodplain.

The 1993 flood caused a serious economic and environmental pest, the zebra mussel, to wash from the Upper Illinois River downstream into the lower Illinois and the Mississippi. In the process, zebra mussel larvae were carried far back into the floodplain and upstream into tributaries that were backed up by the mainstream rivers. Another potential pest was introduced when a fish farm on a tributary of the Mississippi flooded and Asian black carp escaped. The carp is able to consume endangered native mussels and clams and competes with the native fish and ducks that already consume zebra mussels.

The flood moved tremendous amounts of water to the Gulf of Mexico. Through erosion and flooding of agricultural soils throughout the Midwest, the floodwaters picked up vast quantities of various chemicals, including some from flooded industries along the rivers. Substantial quantities of these agricultural (and other) chemicals were transported into the streams and rivers, either as dissolved matter or in suspension, and into the floodplains. This polluted water infiltrated floodplains and contaminated ground water aquifers.

There was an immense discharge of freshwater to the Gulf of Mexico during the summer of 1993. The delivery of this water and its dissolved and suspended materials affected the ecosystem of the Gulf of Mexico. Discharges of herbicides and nitrates to the Gulf of Mexico were substantially higher in 1993 than in prior years, stimulating plankton blooms. When the plankton died and sank, the decaying organic matter used up oxygen in the bottom layer of water, lowering oxygen levels over an area of 6,000 square miles (the so-called "dead zone") and threatening valuable fisheries. The total amount of atrazine delivered to the Gulf of Mexico by the Mississippi River from April to August 1993 was 1.2 million pounds, up about 25 percent from loads delivered during 1992. One million tons of nitrate-nitrogen were discharged to the Gulf of Mexico from April to August 1993, a value 37 percent larger than loads for 1992 (Goolsby et al., 1993).

In summary, the flood of 1993 exacerbated two preexisting environmental problems related to human activity. First, it facilitated the spread of a serious economic and environmental pest, the European zebra mussel, that accidentally had previously been introduced to the St. Lawrence-Great Lakes drainage by transoceanic ships (and facilitated other introduced pests, such as the Asian tiger mosquito). Second, nutrient loading of the Gulf of Mexico was substantially increased by the flood, and the summer "dead zone" in the Gulf consequently expanded, with potential detrimental impacts on the largest fishery in the United States. At the same time, the 1993 flood also vividly demonstrates the complexity and uncertainty over the range of positive and negative impacts upon floodplain ecosystems, as well as the overwhelming task of trying to distill precise figures for the full costs and benefits of an extreme geophysical event.

DROUGHTS

Unlike floods, droughts generally damage ecological systems and yield few offsetting benefits. In fact, the most subtle and enduring impacts of droughts occur in the environment. The cumulative stress on wetlands, wildlife, forests, ground water, and soils cannot be measured accurately, and many effects occur slowly and over a period of years, making them extremely difficult to quantify.

The problems generated by droughts begin with changes in the quantity and quality of water available in the hydrologic system. Drought damages both plant and animal species by depriving them of food and water, increasing their susceptibility to disease, and increasing their vulnerability to predation. As with floods, droughts produce a loss of biodiversity, and often increase erosion of dried soils when rain eventually comes. Droughts also degrade water quality, shifting salt concentration, pH levels and dissolved oxygen, while increasing water temperatures. Even air quality is diminished because of increased dust and pollutants. Droughts also lead to more wildfires, while adversely changing salinity levels in coastal estuaries and reducing the flushing of pollutants.

Drought of 1988. The best documentation of environmental damages from a drought came from studies of the 1988 drought, which affected large portions of the United States. This event caused enormous reductions in streamflows in two major drought-affected regions. Plans to divert additional water from the Great Lakes to enhance the record low flows of the Upper Mississippi River system were halted by environmental concerns over the potential impacts of lowered water levels on the lakes (Changnon, 1989). Many streams were unable to handle industrial discharges and agricultural pollution, greatly limiting water quality and the use of water. Water supplies dropped to seriously low levels in the southeast United States, where many uses of river waters, including hydropower generation and navigation on major rivers, had to be curtailed. Saltwater intrusion up the Mississippi River beyond New Orleans was so severe that underwater sills were built to halt the intrusion.

The 1988 drought led to 68,000 wildfires that burned 5.1 million acres of federal forest land. Fire-fighting costs alone amounted to $300 million. The best-known fires were those in Yellowstone National Park, which captured national attention. The dry conditions in areas adjacent to the fires greatly reduced the number of tree seedlings, with mortality of 40 percent of the trees planted in the 10 years prior to 1988, including 150 million pine seedlings. The drought led to increased insect attacks on commercial forests, and 5.7 billion board feet of lumber were lost because of pine bark beetles. The total loss to U.S. forests was estimated at $5 billion (Riebsame et al., 1991).

The 1988 drought also caused sizable but unmeasured losses of fish, waterfowl, and wildlife. High water temperatures in bays along the East Coast caused an increase in oyster diseases, resulting in an 1988 harvest of 375 million bushels, the lowest on record for Chesapeake Bay (Avery, 1988; Changnon et al., 1996).

Finally, the high temperatures associated with the 1988 drought had profound effects on human health. Several thousands of deaths were attributed directly or indirectly related to the high temperatures. Many of these deaths occurred in the large urban areas of the central and eastern United States. Municipal governments responded by establishing cooling centers. Not surprisingly, a comprehensive study of the environmental impacts of the 1988 drought concluded that there were "no winners" in the ecosystems (Riebsame et al., 1991).

HURRICANES AND TROPICAL STORMS

Hurricanes and tropical storms create environmental damages within paths that vary from 50 to 150 miles in width. The environmental consequences largely consist of damages to trees and underbrush in the storm path. At the same time, the long-term ecosystem damages of these storms are uncertain. To be sure, during coastal storms in particular there is often significant erosion of shores and beaches. In the long run, however, nature generally has adapted to these events, so the extent of negative impacts of these events is not clear.

SEVERE LOCAL STORMS

Severe local thunderstorms—such as a major tornado striking Wichita or a thunderstorm producing large hailstorms in Dallas—are often labeled as natural disasters due to the attendant looses of life and economic losses, but in general these events are localized. They are not events that create serious, large-scale damages to the natural ecosystem. Nonetheless, it is possible that the *cumulative* environmental impacts of severe storms over a period as short as a year can be significant. Broad areas can suffer from numerous forest fires triggered by cloud-to-ground lightning. High winds and hail cause localized damages to plants and forests, although the total losses are considered to be relatively minor on a regional or national scale.

Heavy rains that lead to flash floods also can be environmentally damaging, at least locally. They increase soil erosion rates, and if they occur in mountainous areas the resulting flood can create massive damages to ecosystems in narrow mountain valleys.

EARTHQUAKES

Although the dominant losses from earthquakes are to structures and potentially to humans, these events can also result in adverse environmental consequences. Examples include flora and fauna damaged by the shocks and shifts in land surfaces, as well as alterations in local hydrologic systems. For example, the famed New Madrid earthquake in the central United States in the 19th century changed the course of the Mississippi River and created a cutoff lake. In the most affected areas, trees, shrubs, land cover, and habitats can also be destroyed. There are currently no estimates of the environmental or ecosystem losses from earthquakes (although the national, long-term impact is probably not great).

HIGH WINDS

Strong and persistent synoptic scale (nonstorm) high winds can sweep over large areas and cause damage to trees and plants. High winds can also help promote large-scale fires, typically in dry western areas. Recent wind-driven fire catastrophes in California accounted for insured property losses of $1.5 billion in October 1992, rated as the third largest fire loss in the nation's history (III, 1993). Major brushfires enhanced by strong winds occurred in California in October 1993 and again in November 1993, together causing $815 million in insured property losses (III, 1995). These huge, wind-driven fires consumed all underbrush, ground cover, and trees over hundreds of square miles, but there is no known report documenting the value of these losses to the natural or landscape environments.

High winds and waves caused by severe extratropical cyclones damage beaches and shoreline ecosystems. This is a problem mainly along the East Coast when strong "Nor'easters" strike along shores ranging from 500 to 1,000 miles in length and in the Great Lakes, where winter storms create waves that severely erode beaches. However, these shoreline effects also can be viewed as an inherent part of nature to which coastal ecosystems have adapted.

SUMMARY

Although natural disasters are by definition undesirable for humans, they often carry several ecological benefits. Floods are a prime example of the mixed economic and environmental effects. At the other extreme, droughts not only produce economic damage, but virtually all of their environmental impacts are also undesirable.

There are only limited quantitative data of the environmental costs of natural disasters. Relatively little effort by the private sector, academics and scientists, or the government has gone into this activity. Nonetheless, such studies as have been conducted reveal that numerous environmental problems caused by natural disasters often have significant consequences for ecosystems, and eventually people, societies, and economies. Thus, even though these environmental impacts may not readily translate into monetized losses (or gains) their importance strongly suggests they should be considered by governments, academia, and the private sector in the study and design of hazard mitigation and land use policies.

REFERENCES

Avery, M. 1988. Heat Death Toll in 1988. Washington, D.C.: Center for Environmental Physiology.
Barry, J.M. 1997. Rising Tide. New York: Simon and Schuster.
Bhowmik, N. 1996. Physical effects: A changed landscape. Pp. 101–131 in The Great Flood of 1993. S. Changnon, ed. Boulder, Colo.: Westview Press.
Changnon, S.A. 1996. Lessons from the flood. Pp. 300–319 in The Great Flood of 1993. S. Changnon, ed. Boulder, Colo.: Westview Press.
Changnon, S.A. 1989. The 1988 drought, barges and diversion. Bulletin American Meteorological Society 70:1092–1104.
Changnon, S.A. 1978. How a severe winter impacts individuals. Bulletin American Meteorological Society 60:110–114.
Changnon, S.A. and D. Changnon, 1978. Winter storms and the record-breaking winter in Illinois. Weatherwise 31:218–225.
Changnon, S.A. and W.E. Easterling. 1989. Measuring drought impacts: The Illinois case. Water Resource Bulletin 25:27–42.
Changnon, S. A., K.E. Kunkel, and B. Reinke. 1996. Impacts and responses to the 1995 heat wave: a call to action. Bulletin American Meteorological Society 77:1497–1506.
Goolsby, D. A., W.P. Battaglin, and E. M. Thurman. 1993. Occurrence and Transport of Agricultural Chemicals in the Mississippi River Basin, July Through August 1993. Circular 1120–C, U.S. Geological Survey, Denver Colo.
Insurance Information Institute (III). 1995. The Fact Book 1995: Property/Casualty Insurance Facts. New York: III.
Insurance Information Institute (III). 1993. The Fact Book 1993: Property/Casualty Insurance Facts. New York: III.
Maher, R.J. 1995. Observations of fish community structure and reproductive success in flooded terrestrial habitats during an extreme flood event. Long Term Resource Monitoring Program. TRMP Technical Report 95-T, National Biological Survey, Onalaska, Wisc.
Pielke, R.A., Jr. 1995. Hurricane Andrew in South Florida: Mesoscale Weather and Societal Responses. Boulder, Colo.: National Center for Atmospherics Research.
Pilkey, O.H. and K.L. Dixon. 1996. The Corps and the Shore. Washington, D.C.: Island Press.
Riebsame, W.E., S.A. Changnon, and T.R. Karl. 1991. Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987–89 Drought. Boulder, Colo.: Westview Press.
Sparks, R.E. 1996. Ecosystem effects: positive and negative outcomes. Pp. 132–162 in The Great Flood of 1993. S. Changnon, ed. Boulder, Colo.:Westview Press.

Appendix B

Biographical Sketches of Committee Members

ROBERT E. LITAN (Chair) is the director of the economic studies program at the Brookings Institution, where he served as a senior fellow from 1984 to 1993 and as director of two research centers in the program from 1987 to 1993. He is both an economist and an attorney. In 1972 he received a B.S. in economics (summa cum laude) from the Wharton School of Finance at the University of Pennsylvania. He received a J.D. from Yale Law School (1977) and both his M.Phil. and Ph.D. in economics from Yale University (1987). Dr. Litan has served in several capacities in the federal government. During 1995 and 1996, he was associate director of the Office of Management and Budget (where he was responsible for overseeing budgetary and other policies of six cabinet agencies). From 1993 to 1995, he was deputy assistant attorney general, in charge of civil antitrust litigation and regulatory issues, at the Department of Justice. From 1977 to 1979, he was the regulatory and legal staff specialist for the President's Council of Economic Advisers. From 1982 through 1990, he was affiliated with Powell, Goldstein, Frazer and Murphy, first as a senior associate, then as a partner, and subsequently as counsel.

RICHARD A. ANDREWS is director of the Governor's Office of Emergency Services (OES) in California. He oversees planning and training for all natural, technological, environmental, and terrorist emergencies in the state. Dr. Andrews serves as senior policy adviser on a wide variety of public safety issues, reporting directly to the governor. As director of OES, he has legal responsibility for managing all state resources during major emergencies and has set crisis management policies and strategies for recovery efforts following numerous disaster and emergency declarations. Dr. Andrews received his A.B. from DePauw University and his M.A. and Ph.D. from Northwestern University. He is chair of California's Chemical Emergency Preparedness and Response Commission and has served on two NRC committees: the Committee on Real-Time Earthquake Warning and the United States-Japan Working Group on Urban Earthquake Hazards.

STANLEY A. CHANGNON is professor of atmospheric sciences and geography at the University of Illinois, Urbana-Champaign. He also serves as principal scientist and chief emeritus of the Illinois State Water Survey. Dr. Changnon has participated in four National Research Council studies and is a fellow of the American Association for the Advancement of Science and the American Meteorological Society. He has authored numerous works on weather climate and water resources and has received awards for his contributions to the building sciences, water resources research, and climate change.

LLOYD S. CLUFF is manager of the Geosciences Department at the Pacific Gas and Electric Company and is an expert on the identification of active seismic faults and their potential motions. Mr. Cluff has served the NRC in a number of capacities: as chair of the Committee on Practical Lessons from the Loma Prieta Earthquake, as a member of the U.S. National Committee for the Decade for Natural Disaster Reduction, and as a member of the Board on Earth Sciences. He is a member of the National Academy of Engineering and has served on numerous NRC committees, including the Subcommittee on Earthquake Research and the Committee on Earthquake Engineering Research.

RONALD T. EGUCHI is vice-president and director of the Center for Advanced Planning and Research at EQE International in Irvine, California. He has directed major research and application studies in risk analysis, earthquake engineering, and natural hazards engineering for government agencies and major western and central U.S. utility companies and is on the mayor's blue-ribbon panel that is developing an earthquake hazard mitigation program for the city of Los Angeles. Mr. Eguchi is a member of the American Society of Civil Engineers, the Earthquake Engineering Research, Institute and the Seismic Risk Committee. He received an M.S. degree in Systems and Earthquake Engineering (1975) and a B.S. in Engineering (1974), both from the University of California, Los Angeles.

JAMES F. KIMPEL received his B.S. from Denison University and his M.S. and Ph.D. from the University of Wisconsin-Madison. Dr. Kimpel currently is a professor of meteorology at the University of Oklahoma and director of the National Severe Storms Laboratory. He develops scientific programs in hydrometeorology and remote sensing and works with Next-Generation Radar Operations, the National Severe Storms Laboratory, and others. Dr. Kimpel is a member of the National Academy of Sciences' Board on Natural Disasters, American Meteorological Society and the American Geophysical Union.

ANNE S. KIREMIDJIAN received her Ph.D. in structural engineering from Stanford University, where she is currently a professor in the Department of Civil Engineering and director of the Blume Earthquake Engineering Laboratory. Her research interests are within the area of probabilistic methods in civil engineering. Dr. Kiremidjian specializes in developing models for earthquake occurrences, ground motion characterization, structural damage evaluation, and reliability analysis of structures. She has published over 100 journal papers, technical reports, and conference proceeding papers and has been an invited and keynote speaker at several major conferences, seminars, and professional meetings both on the national and international levels. Dr. Kiremidjian is a member of Earthquake Engineering Research Institute and the American Society of Civil Engineers.

RICHARD J. ROTH JR. is the chief property/casualty actuary for the California Insurance Department, the state agency that regulates all aspects of insurance in California, including solvency and rates. In addition to working on issues related to workers' compensation and other types of insurance (automobile, homeowners), he has taken a special interest in the insurance of natural catastrophes, particularly earthquakes. Mr. Roth administers the surveying of all licensed insurers and reports on their projected earthquake exposures and probable maximum loss, publishing these results and assessing California's earthquake insurance market every two years. He is a fellow and member of the board of directors of the Casualty Actuarial Society and has addressed officials both nationally and internationally on earthquake insurance issues. Mr. Roth has master's degrees in economics and statistics from Stanford University and a law degree from the University of Connecticut.

THOMAS C. SCHELLING is a distinguished professor of economics and public affairs at the University of Maryland and the Lucius N. Littauer Professor of Political Economy, emeritus, at Harvard University. He earned an A.B. in economics from the University of California, Berkeley, and a Ph.D. in economics from Harvard University. He has served in the U.S. Bureau of the Budget, the Economic Cooperation Administration in Europe, and the White House Executive Office of the President. He joined the faculty at Harvard University after serving five years on the faculty at Yale University. He is a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, and the Association for Public Policy Analysis and Management. He is a member of the National Academy of Sciences and the Institute of Medicine. Dr. Schelling currently serves as a member of the NRC's Commission on Geosciences, Environment, and Resources.

RICHARD T. SYLVES is a professor of political science at the University of Delaware and director of the environmental and energy policy graduate program. Dr. Sylves has focused his career on the politics and policies of disaster management. He currently serves as principle investigator for three disaster studies: "Economics of Disaster Instructor Guide"; "Politics of Disaster Instructor Guide"; and "Disasters and Coastal Zone States: A Policy Analysis." Dr. Sylves received his Ph.D. in political science from the University of Illinois at Urbana-Champaign in 1978.

CAROL TAYLOR WEST is professor and chair of the Department of Economics at the University of Florida. Her primary research interests include regional economic analysis and forecasting, applied microeconomic theory; and mineral economics. She has been a member of the State of Florida's Comprehensive Plan Committee and currently serves on the Florida Commission on Hurricane Loss Projection Methodology. Dr. Taylor West received her Ph.D. in economics from the University of Michigan in 1974 and her B.A. from Harvard College in 1967.